SPATIAL ANALYSIS
A Guide for Ecologists

The spatial and temporal dimensions of ecological phenomena have always been inherent in the conceptual framework of ecology, but it is only recently that they have been incorporated explicitly into ecological theory, sampling design, experimental design and models. The number and variety of statistical techniques for spatial analysis of ecological data are burgeoning and many ecologists are unfamiliar with what is available and how the techniques should be used correctly. This book gives an overview of the wide range of spatial statistics available to analyse ecological data, and provides advice and guidance for graduate students and practising researchers who are either about to embark on spatial analysis in ecological studies or who have started but are unsure how to proceed. Only a basic understanding of statistics is assumed and many schematic illustrations are given to complement or replace mathematical technicalities, making the book accessible to ecologists wishing to enter this important and fast-growing field for the first time.

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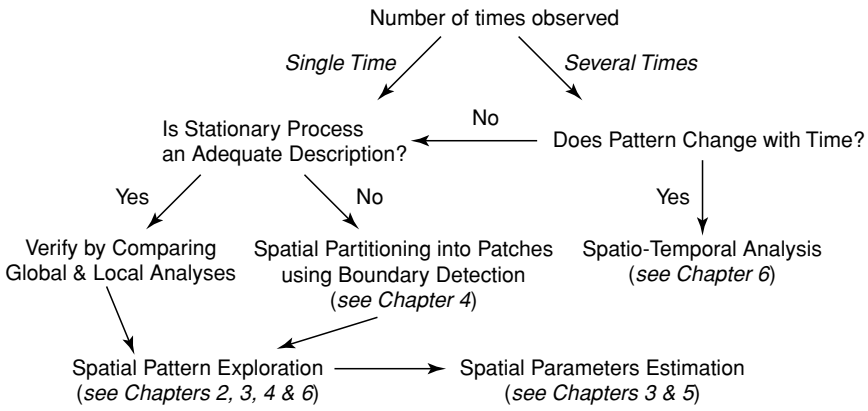
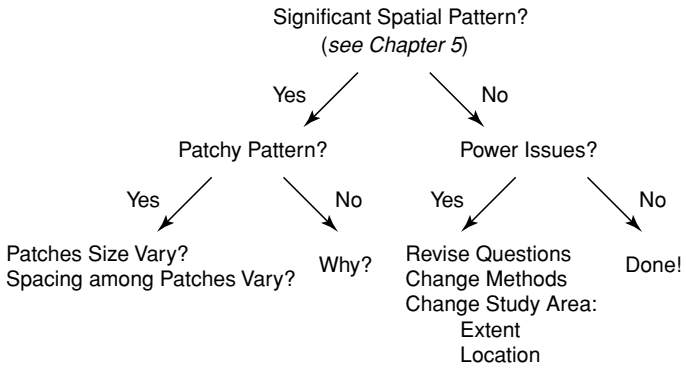


Decision-Tree of the Spatial Analyses Presented in the Book



Key Questions to Ask while Analysing Spatial Ecological Data

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À Ferko et à Ian
To Phyllis, John and Martha

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Preface

Spatial analysis has become the most rapidly growing field in ecology. This popularity is directly related to at least three factors: (1) a growing awareness among ecologists that it is important to include spatial structure in ecological thinking; (2) the alteration of landscapes around us at an increasing rate, which requires a constant re-evaluation of their spatial heterogeneity; and (3) the availability of software designed specifically to perform spatial analyses. One major problem with spatial statistics software is that they are often not used correctly. Incorrect application arises because: (1) ecologists have not been properly trained about issues of scale; and (2) ecologists do not realize fully the implications of the fact that spatially autocorrelated data are not independent, and thus violate the assumptions of the familiar parametric statistics. The purpose of this book is to fill the gap between the current need for spatial analysis and the uncertainty of many ecologists on how to perform these kinds of analysis correctly.

The motivation for this book is as the title suggests; it is intended as a guide for ecologists through the large array of methods available for spatial analysis. Given that the scope of this book is quite broad, it is not as specialized as Dale (1999), which concentrates on the analysis of static spatial pattern. 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 be a useful guide to 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 treads that link them together, including the application of methods and their usefulness in addressing ecological questions. Our goal is to provide a broad overview, as much as possible, of the various well-established spatial methods. Hence, we do not provide much of the theoretical background or mathematical derivations (which are both available elsewhere, in more specialized texts such as Cressie 1993); but 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 in print; 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 a better understanding of the complexity of nature and how it works, by testing hypotheses about ecological processes 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 to disentangle the complexity of natural systems. Thus, the ecological motivation for performing spatial analysis is to detect pattern, but that is only the beginning of **answering a bigger question**. Ecologists then want to understand the process that generates the pattern. Geographers are probably like ecologists in that the description 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, the NCEAS working group on '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, Patrick James, Stephanie Melles and Agnes Wong; editing the various versions of the text: Gillian Forbes, Stephanie Melles and Rebecca Torretti; carrying out the spatial analyses of the data: 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).

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