References: Spatial Point Pattern Analysis

Reference Books:

Baddeley, A. et al. 2006. *Case Studies in Spatial Point Process Modeling.* Springer-Verlag.

Review of current theory, followed by short chapters on very recent methods development, followed by a diverse set of examples (archeology, cells in tissues, disease outbreaks, animal herds, and earthquakes).

Cressie, N. A. C. 1991, *Statistics for Spatial Data*, Wiley, New York.

Comprehensive, theoretical treatment of all types of spatial statistics. Chapter 8 deals with point patterns.

Diggle, P. J. 2003, *Statistical Analysis of Spatial Point Patterns*, 2nd ed., Academic Press, New York.

Very readable with a good mix of theory and example. Covers exploratory analysis, estimation using K(t), likelihood-based estimation, and other topics. Examples are ecological and epidemiological. My current favorite

Lawson, A. 2002. *Spatial Epidemiology.* Wiley, New York.

Theory and examples of understanding disease patterns using either location or count data.

Stoyan, D. and Stoyan, H. 1994. *Fractals, Random Shapes and Point Fields*, John Wiley, Chichester. English translation of Stoyan, D. and Stoyan, H. 1992. *Fractale-Formen-Punktfelder. Methoden der Geometrie-Statistic.* Akademie Verlag GmbH. Berlin.

Part 3 (last half of book) is a good introduction to point pattern analysis. Treatment of pair correlation function = derivative of K(t) is especially good.

Upton, G. J. G. and Fingleton, B. 1985. *Spatial Data Analysis by Example, Volume 1. Point pattern and quantitative data* Wiley, Chichester.

A bit old now, but a nice biologist-friendly introduction to the methods. Very little theory.

Ecological Examples:

Duncan, R. P. 1993. Testing for life historical changes in spatial patterns of four tropical tree species in Westland, New Zealand, *Journal of Ecology* 81, 403-416.

Uses Ripley's K(t)

Fisher JB, et al. 2007. An analysis of spatial clustering and implications for wildlife management: A burrowing owl example. *Environmental Management* 39:403-411

Compares patterns in nest locations to patterns in management activities.

Haase, P. 1995. Spatial pattern analysis in ecology based on Ripley's K-function: Introduction and methods of edge correction. J. Vegetation Science 6:575-582.

Introduction to K(t) for biologists.

Lancaster J and Downes BJ 2004. Spatial point pattern analysis of available and exploited resources *Ecography* 27:94-102

Uses non-edge-corrected estimators and evaluates two models: CSR and an ecological "null" model.

Perry GLW, Miller BP, and Enright NJ. 2006. A comparison of methods for the statistical analysis of spatial point patterns in plant ecology. *Plant Ecology* 187:59-82

Overview of a variety of approaches, including recent developments in local versions of K(t) and pair-correlation functions (which they call neighborhood density function).

Peterson, C. J. and Squiers, E. R. 1995 An unexpected change in spatial pattern across 10 years in an Aspen-White Pine forest, *Journal of Ecology* 83, 847-855.

Stamp, N. E. and Lucas, J. R. 1990, Spatial patterns and dispersal distance of explosively dispersing plants in Florida sandhill vegetation, *Journal of Ecology* 78, 589-600.

Estimates dispersal distance by fitting Neyman-Scott process.

Stoyan, D. and Penttinen, A. 2000, Recent applications of point process methods in forestry statistics. *Statistical Science* 15, 61-78.

Review paper on forestry applications, emphasizing K(t) and pair correlation functions.

Wiegand T, Gunatilleke S, and Gunatilleke N. 2007. Species associations in a heterogeneous Sri lankan dipterocarp forest *American Naturalist* 170: E67-E95

Comparisons of a large number of species pairs in a tropical forest. Partitions pattern into interactions (2nd order) and environment (1st order).

Wiegand T, and Moloney KA. 2004. Rings, circles, and null-models for point pattern analysis in ecology *Oikos* 104: 209-229.

Compares a variety of ways to examine patterns at specific scales.

Statistical Aspects / Nearest-neighbor methods:

Cuzick, J. and Edwards, R. 1990, Spatial clustering for inhomogeneous populations (with discussion), *Journal of the Royal Statistical Society, Series B* 52, 73-104.

Detailed theory of nearest-neighbor tests. Prooves asymptotic normality of N_{AA}. Application is clustering of rare diseases.

Clark, P. J. and Evans, F. C. 1954, Distance to nearest neighbor as a measure of spatial relationships in populations. Ecology, 35, 445-453.

Mean NN distance as a test for spatial randomness. Ignored edge effects

Donnelly, K. P. 1978. Simulations to determine the variance and edge effect of total nearest-neighbour distance. pp 91-95 in Hodder, I. (ed.) *Simulation Studies in Archaeology.* Cambridge University Press, Cambridge.

Corrections to mean NN distance and Var NN distance for edge effects in square and rectangular regions.

Gignoux, J., Duby, C. and Barot, S. 1999. Comparing the performance of Diggle's tests of spatial randomness for small samples with and without edge-effect correction: application to ecological data. Biometrics, 55, 156-164.

Argues for Monte-Carlo tests without edge corrections because they are more powerful.

Pielou, E. C. 1961. Segregation and symmetry in two-species populations as studied by nearest-neighbour relationships. Journal of Ecology, 49, 255-269.

Original paper of nearest-neighbor contingency table. The Chi-square test proposed here is not appropriate for completely mapped data.

Simberloff, D. 1979, Nearest neighbor assessments of spatial configurations of circles rather than points. Ecology, 60, 679-685.

Properties of NN distance when events occupy areas that can not overlap.

Statistical Aspects / Multitype patterns:

Diggle, P. J. and Chetwynd, A. G. 1991, Second-order analysis of spatial clustering for inhomogeneous populations, *Biometrics* 47, 1155-1163.

Bivariate Ripley's K(t) to look at clustering of rare diseases. Uses $K_{AA}(t) - K_{BB}(t)$, since interested in whether disease is more clustered than background population.

Dixon, P. M. 1994. Testing spatial segregation using a nearest-neighbor contingency table. Ecology, 75, 1940-1948.

Derives E N_{ij}, Var N_{ij}, and Cov N_{ij}, N_{kl} for completely mapped data. Focus on nearest-neighbor contingency table for two types of points.

Dixon, P. M. 2002. Nearest-neighbor contingency table analysis of spatial segregation for several species. Ecoscience 9:142- 151.

Details and examples of nearest-neighbor contingency tables for more than two types of points.

Statistical Aspects / Ripley's K(t):

Baddeley, A. J. and Silverman, B. W. 1984, A cautionary example on the use of second-order methods for analyzing point patterns. Biometrics 40, 1089-1093.

Illustrates that Ripley's K(t) does not uniquely identify a spatial process.

Doguwa, S. I. and Upton, G. J. G. 1989, Edge-corrected estimators for the reduced second moment measure of point processes. *Biometrical Journal* 31, 563-576.

Comparison of various ways of correcting for edge effects

Ripley, B. D. 1977, Modelling spatial patterns, *Journal of the Royal Statistical Society, Series B* 39, 172-192.

One of the first papers on K(t), by its developer

Statistical Aspects / Monte-Carlo tests:

Besag, J. and Diggle, P. J. 1977, Simple Monte Carlo tests for spatial pattern. *Applied Statistics* 26, 327-333.

Diggle, P. J. and Gratton, R. J. 1984, Monte Carlo methods of inference for implicit statistical models (with discussion). *Journal of the Royal Statistical Society, Series B* 46, 193-227.

Discussion of how to fit a model (e.g. K(t)) when model can not be written down in closed form, e.g. as K(t) = function of parm. Idea is to estimate E K(t) using simulation.

Miscellaneous spatial pattern references:

Baddeley, A. and Turner, R. 2000. Practical maximum pseudolikelihood for spatial point patterns. *Australian and New Zealand Journal of Statistics* 42:283-322.

Theory for parameter estimation in variety of point processes (heterogenous Poisson, clustering, repulsion)

Rathbun, S. L. 1996. Estimation of Poisson intensity using partially observed concomitant variables. *Biometrics* 52, 226-242.

Method to relate local density to a predictor that is only observed at certain locations. Combines kriging with point processes.

Syrjala, S. E. 1996. A statistical test for a difference between the spatial distributions of two populations. Ecology 71:75-80.

Given data on X at a set of locations and Y at a set of locations, is the spatial pattern the same? Uses a randomization test on cumulative frequency distributions.

Software:

Kaluzny, S. P., Vega, S. C., Cardoso, R. P. and Shelly, A. A. 1996. *S+SPATIALSTATS User's Manual, Version 1.0.* MathSoft Inc, Seattle, WA.

Add-on module for Splus. It is available at ISU by typing module(spatial) in your Splus session. It includes point pattern and variogram functions.

Moser, E. B. 1987, The analysis of mapped spatial point patterns. *Proceedings of the 12th Annual SAS Users Group International Conference* 12, 1141-1145.

SAS macros for K functions. To use, you need to download, then include in your SAS program. The URL to download (as of Spring 2001) is
http://www.stat.lsu.edu/faculty/moser/spatial/spatial.html Not nearly as extensive as the Splus/R functions.

Rowlinson, B.S. and Diggle, P. J. 1992, *Splancs: Spatial Point Pattern Analysis Code in S-Plus.* Technical Report 92/63, Lancaster University, U.K.

Publically available Splus / R library. I find this easier to use for point pattern analysis than SpatialStats. Splancs and spatstat do many similar things. Splancs is better at randomization tests (faster) and has functions for space-time point patterns. Sampling regions must be convex polygons. Rectangles are fine.

Baddeley, A.O. and Turner, R. Spatstat

An alternative Splus / R library. Spatstat emphasizes model fitting using maximum pseudo-likelihood. Does have an extensive collection of exploratory analyses for univariate and marked point processes. Allows a very general sampling regions, including concave polygons, 'holes' in the sampling region, and regions specified by a GIS-like raster map.