

**References: Spatial Point Pattern Analysis**

## Reference Books:

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  $K(t)$

Gaines, K.F., Bryan, A.L. Jr, and Dixon, P.M. 2000. The effects of drought on foraging habitat selection in breeding wood storks in coastal Georgia. *Waterbirds* 23, 64-73.

Uses nearest-neighbor contingency table. Warning: sample size is very small in this paper. Preferable to have much larger N.

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.

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.

#### 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  $E N_{ij}$ ,  $\text{Var } N_{ij}$ , and  $\text{Cov } N_{ij}, N_{kl}$  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  $K(t) = \text{function of parm.}$  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.

## Geostatistics, Variograms and Kriging: References

Isaaks, E. H. and Srivastava, R. M. 1989. *An Introduction to Applied Geostatistics*. Oxford Univ. Press, New York

Introduction to variograms and kriging with an extended example.

Griffith, D. A. and Layne, L. J. 1999. *A Casebook for Spatial Statistical Data Analysis*. Oxford University Press, New York.

Uses examples to compare various approaches to modelling spatial data and spatial 'experiments'. Includes variograms and various ANOVA-like models that include spatial dependence.

Gross, K. L., Pregitzer, K. S., and Burton, A. J. 1995. Spatial Variation in Nitrogen Availability in Three Successional Plant Communities. *J. Ecology*, 83:357-367.

Uses variograms of soil N to compare spatial patterns of N in three fields along a successional gradient.

Rossi, R.E., Mulla, D. J., Journel, A. G., and Franz, E.H. 1992. Geostatistical tools for modeling and interpreting ecological spatial dependence. *Ecological Monographs* 62:277-314.

Describes ecological applications of variograms, then presents various extensions: variograms for presence/absence data, robust variograms, 'non-ergodic' variograms.

Underwood, A. J. and Chapman, M. G. 1996. Scales of spatial patterns of distribution of intertidal invertebrates. *Oecologia* 107:212-224.

Uses spatial correlograms and other techniques to compare spatial patterns between species and between sites.