Anisotropy in spatial point patterns: applications to ecology

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Ecologists are concerned primarily with the study of interactions. How do species interact with other species? How do species interact with their physical environment? To answer these questions one must consider how species are distributed spatially.

Spatial point process techniques can potentially address these questions, providing the tools to both mathematically and statistically model spatial data. Yet despite their apparent applicability, few researchers truly embrace these techniques (Illian et al. 2009; Law et al. 2009). One problem with spatial point process techniques is their inability to deal with ecological data. In particular, a number of assumptions are made, assumptions that rarely hold for ecological data.

One such assumption is isotropy, which states that there is no directional structure in the pattern of points. As a result of resource gradients, or even potentially as a result of inter- and intra-specific interactions, this assumption rarely holds for ecological data. In this project, I developed a method for estimating a second-order characteristic of anisotropic point patterns, and explored how these estimates could be used to make ecological inferences. It must be stressed that this method was intended for use as an exploratory data analysis tool; earlier studies consider statistical testing of isotropy (Guan et al, 2006). I restricted this project to the study of sessile organisms (particularly plants), as spatial distributions for these organisms more directly represent interactions than for mobile organisms.

The second-order product density was studied, as it (loosely) represents how one point "sees" the world around it (described as the "plants-eye view" in Law et al. 2009). To estimate this characteristic for anisotropic data, I followed the method of Guan et al (2006), who use a kernel weight function to consider the second-order product density in a particular direction (e.g. how the trees in a forest see their world to the northeast). I modified this to consider the second-order product density as a function of distance, and estimated this characteristic from subsets of the data to obtain replicate functions.

These replicate functions contain a large amount of information about a given point process, but are too numerous to facilitate easy interpretation. To address this, functional data analysis (FDA) was used to further analyse these functions, providing ecologically-meaningful interpretations (see Ramsay and Silverman, 1997 for an introduction to FDA;

Illian et al., 2006 illustrate an ecological application of FDA to spatial point processes). Two techniques were found to be particularly relevant; functional principal components analysis (FPCA), and functional canonical correlation analysis (FCCA). FPCA uses variability as a criterion for reducing data to lower dimensions, which allows distinction between plant taxa that respond to different directional gradients. For example, plants that are superficially identical (i.e. same densities and general locations) may be responding to different resources on a small scale, resulting in different directional structures. This technique detects such directional structures, highlighting spatial differences not considered by existing techniques. Similarly, FCCA considers the correlation between two sets of functional data, allowing assessment of the relationship between a particular plant taxon and underlying resource distributions. These results may further illuminate the relationships between plant taxa and environmental resources (light, moisture, nutrients).

Many ecological questions can be addressed using these techniques. In particular, questions of species coexistence may be answered by better determining the limiting resources for a given plant taxon. This is a major area of study for ecologists, and the availability of simple exploratory tools is a starting point for the development of more advanced techniques.

As an ecology student, the AMSI vacation scholarship program has given me the opportunity to experience the world of mathematics and statistics. The insight gained from this experience will no doubt carry through into my future studies. In particular, the Big Day In program exposed me to other areas of mathematics (and science in general), as well as giving me the opportunity to present my work to students and professionals from the world of science. I sincerely thank AMSI for this opportunity, and also wish to acknowledge the generous support of CSIRO.

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