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Ecology and Space: An Approach from Point Patterns

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Review Article

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ABSTRACT

Spatial point patterns in plant ecology are generally defined in two-dimensional space, where each point is denoted by an ordered pair that summarizes the spatial location of a plant. Spatial point patterns are essential because they arise in response to important ecological processes, associated with the structure of a population or community. Such processes basically include seed dispersal, competition for resources, facilitation, and plant response to stress.

In this paper, various factors and potential underlying processes are reviewed to explain the importance of spatial patterns in plant biodiversity. An example is provided wherein spatial point patterns area applied to understand the dispersal of a parasitic plant in central Spain in order to infer secondary vectors about the dispersal syndrome.

INTRODUCTION

In natural communities, random spatial patterns of plants are the exception rather than the rule. Plants are generally arranged further from or closer to one another than expected by chance [1-3]. Understanding the causes and consequences of these spatial patterns currently constitutes an important goal in plant ecology [4,5]. Spatial distributions of organisms, abiotic factors, and ecological interactions play a fundamental role in maintaining the structure, functioning, and dynamics of ecosystems [2].

Analysis of spatial point patterns is of vital importance because ecological processes can give rise to predictable spatial structures, thereby allowing us to understand the mechanisms that control species. Different spatial pattern are associated with different ecological processes, for example, regular patterns are interpreted as indicators of strong competition between plants due to resource constraints [6,7]. Aggregated pattern is evidence of neutral or positive interactions, with distributions in form of patches [8-10]. With the development of new inference methods from ecological processes, studies based on spatial point processes that have modeled the effect of spatial structure on plant communities, have increased considerably [11-15]. Without neglecting the complexity of the relationship between plant pattern and ecological processes [15,16]. Under the name of spatial analysis, a set of techniques is used to quantitatively analyze spatially explicit data [17,18].

Statistical analysis of spatial patterns can be presented in three basic forms: (1) quantitative data analyzed by geostatistical techniques, (2) categorical data represented by maps separated into different areas, as used in the field of landscape ecology, and (3) spatial point patterns related to the location of objects in space. The present review is oriented to the analysis of information presented in the form of point patterns [19].

LITERATURE REVIEW

Point Patterns

Classic approaches

The scientific literature mentions some basic approaches related to the emergence of the theory of point processes, including life tables, counting problems, communication engineering and particle physics [20]. The focus that prevails in high-dimensional spaces is the counting of events in intervals or regions of various types related to discrete distributions. Point processes are one of the processes in which points occur completely randomly in a defined sense; a particular case of which is a Poisson process [21]. The use of distance as a measure of the spatial relationship between individuals of a population was an important contribution to the

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development of statistical methods used to analyze points processes. In particular, provided pioneering work on the application of point processes to plant ecology by using point-plant distances in the study of population patterns. Applications were developed in other areas such as epidemiology and neurophysiology [22-27].

Although the homogeneous Poisson process was one of the first models used to solve problems related to point processes, it was soon discovered that it was feasible to construct another class of models to explain spatial clustering. The first application of such grouped processes is attributed to Neyman [28]. Further attempts at a comprehensive analysis of point patterns were made by Bartlett in the 1960s, who proposed the use of a two-dimensional spectrum of all inter-point distances of a spatial pattern, which allowed the development of tests at different scales [29]. Possibly this motivated Brian D. Ripley to introduce second-order techniques, including the main reduced second-order measure, or K-function; which was later modified and extended [30-34]. Along this line, a clustering model based on inter-point distances was also developed [35]. In addition, the definition of Ripley's K function has been extended to non-stationary processes [36].

In 1978, Arthur Getis and Barry Boots published an important book called “Models of Spatial Processes”, which proposed a formal analysis of point patterns with specific characteristics such as grouping, inhibition and statistical tests [37]. The motivation to develop second-order theories arose from the fact that one or several unique measures between one point and another point are insufficient to summarize a set of data in the form of dot pattern. The goal was to find a cumulative distribution function based on all distances between pairs of points, an approach known as second-order or second order analysis, this set of methods was developed for the analysis of data from exhaustive maps representing locations of all individuals.

Current approaches

A seminal study covering methodological topics related to statistical analysis of spatial point patterns of points and their applications to biological data was provided [38,39]. The approach adopted by Diggle is based on stochastic models, which assume that events are generated by some underlying random mechanism. Point processes are considered as mathematical models for irregular or random point patterns [40]. In some studies, spatial pattern analysis is used to evaluate hypotheses about the processes responsible for observed patterns [41]. To understand these functional processes, it is necessary to identify the spatial and temporal scales at which they occur [42]. But in spite of being inherent to the processes, the explicit inclusion of the scale has been made in the last three decades [43]. At sufficiently large scales, the natural environment exhibits heterogeneity which tends to produce aggregate patterns [38]. Such spatial and temporal characteristics allow us to attribute to underlying processes such as establishment, growth, competition, reproduction, senescence, and mortality [44].

DISCUSSION

For some decades, ecologists have been asking the question: What determines the number, relative abundance, and particular combination of species found in biological communities? The most accepted response includes the influence of biotic and environmental factors [45]. An effective methodology is the verification of the hypotheses by the use of statistical procedures which provides a plausible explanation for the observations. This implies the need to evaluate the potency or significance of the observed pattern, in the face of a properly presented null (theoretical) model, allowing for the randomization of ecological data [46].

Case study: Dispersal of *Arceuthobium oxycedri* in Central Spain

One of the fundamental objectives in ecology is understands spatial patterns of organisms and communities, this can be done through the development of new spatial analysis tools to test innovative hypotheses about the ecology of populations and communities. Acknowledging the limitations of existing methodology for testing ecological hypotheses, a new model for marked point patterns was developed and applied to the dispersal of a parasitic plant native to Spain, *Arceuthobium oxycedri* [47,48]. Null models with biological sense based on dispersal and contagion capacity of the species were constructed using epidemiological control methods and density functions based on dispersal distances were used [49]. The results revealed another secondary dispersal vector of the parasite. While further observational and experimental work is needed to clarify the mechanisms underlying the species’ infection patterns. Spatially explicit dispersal and distribution models can contribute to decision-making processes for forest managers. Management of dwarf mistletoes relies on scientific understanding of the ecology and epidemiology of these important pathogens in the context of on-the-ground forest conditions.

CONCLUSION

In the last two decades, spatial point pattern analysis has been strongly incorporated into ecological studies, however, we can ensure that a large number of spatial point patterns studies and techniques are still underused. Despite of all the approximations, it is suggested that spatial null models in combination with empirical studies have a great potential to increase understanding of mechanisms underlying plant dispersal, and many branches of ecology.

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