EFFECTS OF HETEROGENIETY ON SPATIAL PATTERN ANALYSIS OF WILD PISTACHIO TREES IN ZAGROS WOODLANDS, IRAN

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ABSTRACT:

Vegetation heterogeneity biases second-order summary statistics, e.g., Ripley's *K*-function, applied for spatial pattern analysis in ecology. Second-order investigation based on Ripley's *K*-function and related statistics (i.e., *L*- and pair correlation function *g*) is widely used in ecology to develop hypothesis on underlying processes by characterizing spatial patterns of vegetation. The aim of this study was to demonstrate effects of underlying heterogeneity of wild pistachio (*Pistacia atlantica* Desf.) trees on the second-order summary statistics of point pattern analysis in a part of Zagros woodlands, Iran. The spatial distribution of 431 wild pistachio trees was accurately mapped in a 40 ha stand in the Wild Pistachio & Almond Research Site, Fars province, Iran. Three commonly used second-order summary statistics (i.e., *K*-, *L*-, and *g*-functions) were applied to analyse their spatial pattern. The two-sample Kolmogorov-Smirnov goodness-of-fit test showed that the observed pattern significantly followed an inhomogeneous Poisson process null model in the study region. The results also showed that heterogeneous pattern of wild pistachio trees biased the homogeneous form of *K*-, *L*-, and *g*-functions, demonstrating a stronger aggregation of the trees at the scales of 0-50 *m* than actually existed and an aggregation at scales of 150-200 *m*, while regularly distributed. Consequently, we showed that heterogeneity of point patterns may bias the results of homogeneous second-order summary statistics and we also suggested applying inhomogeneous summary statistics with related null models for spatial pattern analysis of heterogeneous vegetations.

1. INTRODUCTION

In general, point pattern analysis (PPA) of geospatial data is an investigation focused on finding patterns of points indicating the locations of individuals in a defined spatial region. The application of PPA in natural systems reflects the underlying ecological processes that cause their pattern in a two-dimensional space, e.g. spatial distribution of trees in forests that discovers meaningful relationships among trees and their environment (Krebs, 1999; Dale et al., 2002; Brown et al., 2011). Spatial distribution of trees in a forest stand reveals intraspecific and interspecific interactions of them and their relationships with environmental conditions, and thus it is not only a spatial property of trees but also basic quantitative characteristics of them. It also can be used to assess whether groups of trees in a forest stand show competitive or facilitative effects (Uuttera et al., 1998; Fan and Hsieh, 2010; Zhang et al., 2010; Alvarez et al., 2011; Wiegand et al., 2012). If competition is the reason of the spatial distribution of trees in a stand, the arrangement of them tends to be dispersed (i.e., uniform distances between trees), and if facilitation is of great importance, the arrangement tends to be clustered, and it is more likely random if neither facilitation nor competition effects are observed (Wiegand and Moloney, 2004).

Investigation of spatial distribution of trees in fragile ecosystems is very important because of their complicated interactions with each other and their environment, e.g., wild pistachio trees grown in Zagros semi-arid woodlands, Iran. Research in these woodlands has largely focused on mapping and quantitative measurements by remotely sensed datasets (Erfanifard et al., 2007; Bayat et al., 2010); however, ecological relationships of woody species with each other and their environment are still not well studied.

Zagros woodlands, west Iran, cover a vast area of Zagros Mountains stretching from Western Azerbaijan province in the northwest, to the vicinity of Fars province in the southwest of Iran, having an average width and length of 200 and 1,300 *km*, respectively. Classified as semi-arid, Zagros woodlands cover 5 million hectares and consist 40% of Iran vegetation cover. Wild pistachio (*Pistacia atlantica* Desf.) trees, as the second most common tree species of these woodlands, are scattered in many parts of the area mostly mixed with Persian oak (*Quercus brantii* var. *persica*) and almond (*Amygdalus* spp.) trees and sometimes, form pure stands (Jazirehi and Ebrahimi Rostaghi, 2003; Pourreza et al., 2008). Despite relatively low net primary production rates, Zagros woodlands are ecologically important due to their effects on conservation of water sources, prevention of soil degradation and desertification.

Since most ecological processes in natural ecosystems are scale dependent, it is necessary to apply techniques that can detect spatial correlation of points over a range of scales in PPA. Two completely different groups of methods have been developed to quantify the patterns of points in a pre-defined region in different spatial scales. First-order summary statistics explain the intensity of points in the region, while second-order summary statistics describe the distribution of distances between pairs of points. Ripley's *K*-function (and *L*-function as its linear form) and the pair correlation function *g* are a number of the commonly used second-order summary statistics that explain the characteristics of point patterns over a range of spatial scales (Goreaud and Pelissier, 1999; Wiegand and Moloney, 2004; Illian et al., 2008).

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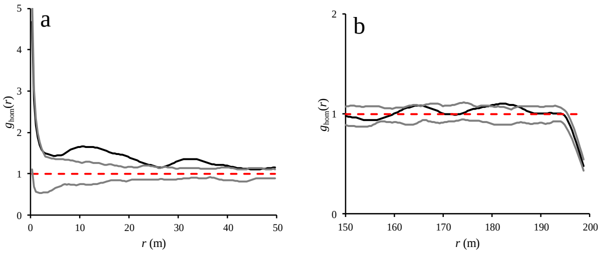

Figure 10. Homogeneous *g*-function at scales of 0-50 *m* (a) and 150-200 *m* (b) for heterogeneous pattern of wild pistachio trees.

4. CONCLUSION

In this article, we investigated how heterogeneity biases the results of the commonly used summary statistics applied in spatial pattern analysis (i.e., *K*-, *L*-, and *g*-functions) in vegetation ecology. In recent years, a variety of first- and second-order summary statistics have been developed in point pattern analysis by many statisticians that are utilized in ecology (Fortin and Dale, 2005; Getzin et al., 2006; Guo et al., 2013). Although ecologists have not used the full range of summary statistics that is available, Ripley's *K*-function and related summary statistics (*L*- and *g*-functions) have been increasingly applied in the literature (e.g., Longuetaud et al., 2008; Alvarez et al., 2011; Cisz et al., 2013). Methods in PPA based on second-order statistics are developed to analyse homogeneous point patterns with the null model of CSR and their application to heterogeneous point patterns biases the results. Most ecologists have used the simplest form that is the homogeneous ones with the null model of CSR as the mathematical tools, especially parameter fitting and finding a suitable edge correction method can be complicated. It addresses practical problems and pitfalls in PPA of plants in vegetation ecology.

To reveal the difficulties that might happen when using homogeneous summary statistics in heterogeneous patterns to ecologists, we applied homogeneous second-order statistics to the heterogeneous point pattern of wild pistachio trees in Zagros woodlands, Iran. We also reviewed inhomogeneous second-order statistics account for heterogeneity in the study region.

Our application of homogeneous *K*-, *L*-, and *g*-functions to wild pistachio trees clearly showed that the results were biased due to the underlying heterogeneity of the pattern revealed by Kolmogorov-Smirnov goodness-of-fit test. Heterogeneity had also a marked impact on the shape of the summary statistics and on the confidence envelopes (Fig. 6, 8, 10). The *K*- and *L*- functions indicated a stronger aggregation at scales of 0-50 *m* than actually existed (Fig. 6a, 8a). The *g*-function also indicated no random distribution, observed in the pattern at scales of 0-50 *m* (Fig. 10a). Although wild pistachio trees were regularly distributed in the study region at scales of 150-200 *m*, the *K*- and *L*- functions showed a significant aggregation at these scales (Fig. 6b, 8b). The pair correlation function *g* also showed randomness at smaller scales of 150-200 *m* (Fig. 10b), while regular distribution of the trees was observed at scales of 150-162 *m* (Fig. 9b).

Heterogeneity of study region detected by suitable tests, i.e. Kolmogorov-Smirnov goodness-of-fit test biased the results of homogeneous summary statistics. To avoid this problem, a null model that acknowledges the heterogeneity (e.g., inhomogeneous Poisson process) has to be applied. Alternatively, homogeneous sub-regions may be examined by homogeneous statistics in the heterogeneous pattern (Perry et al., 2006; Illian et al., 2008; Guo et al., 2013).

Inhomogeneous Ripley's *K*-, *L*-, and *g*-functions with the null model of inhomogeneous Poisson process were also applied to characterize the spatial pattern of wild pistachio trees in the study region. For the PPA of the trees both, inhomogeneous *K*- and *L*-functions, revealed a weak aggregation up to scale 50 *m* (Fig. 5a, 7a) and an approximate regularity at scales of 150-200 *m* (Fig. 5b, 7b). The pair correlation function *g*, also indicated aggregation at scales of 5-21 *m* (Fig. 9a) and regularity of the pattern at scales of 150-162 (Fig. 9b).

Ripley's *K*-, *L*-, and the pair correlation function *g* described the characteristics of pattern of wild pistachio trees over a range of spatial scales; however, *g*-function indicated more detailed changes of the pattern at different scales (Fig. 9). Because of its non-accumulative property, *g*-function is recommended for exploratory point pattern analysis to recognize specific scales at which deviation from a null model happens (Ripley, 1976; Stoyan and Stoyan, 1994; Diggle, 2003; Illian et al., 2008).

In conclusion, we provided a comprehensive analysis on the effects of heterogeneity of wild pistachio trees on the results of second-order summary statistics. The results showed that spatial variation in the intensity of wild pistachio trees induced a systematic bias in the homogeneous forms of *K*-, *L*-, and *g*-functions, demonstrating a stronger aggregation at the scales of 0-50 *m* than actually existed and an aggregation at scales of 150-200 *m*, while they were regularly distributed. This implied the importance of heterogeneity tests prior to PPA in ecology to apply suitable summary statistics and null models.

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