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An assessment of the O-ring methodology using virgin stands of mixed European beech – Sessile oak

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ABSTRACT

Studies aiming at assessment of factors influencing the interdependence among species often rely on assumptions that can significantly change the results. The goal of this study is to evaluate the impact of analytical assumptions on spatial arrangements of trees within mixed species stands. We used the O-ring statistics computed for two species with different shade tolerances (i.e., *Fagus sylvatica* L. and *Quercus petraea* L.). The *O*-ring parameters (i.e., inside radius and width) were evaluated within a replicated design. It was found that inference depends on both radius and width of the ring. We found a sinusoidal dependence between species, with repulsion prevalent at distances less than 1.5 heights of the dominant trees. Same species seems to aggregate at distances ½ height of the dominant trees, and repulse at small and large distances (approximately 8 m and $\geqslant$30 m, respectively). Different species could assist one – another in establishing the spatial arrangement of the stand, but do not help each-other when size is of importance, as competition for common resources is stronger than for the non-common ones. Using *reductio ad absurdum* we found that width of the ring could change the interpretation. For the mixture European beech – sessile oak narrow rings should be used for research focused on location while wider rings are suited to size related analyses. Employment of inadequate values for analytical tools, such as ring width, can fail to reveal spatial relationships. The existence of parameter values that capture better particular processes indicates that different hypotheses should be investigated considering some intrinsic properties of the analysed processes.

1. Introduction

Brundtland report (The World Commission on Environment and Development, 1987) changed the emphasis placed on mixed species stands, by formally acknowledging the importance of sustainability. The report advocates for management strategies that balance the need for economic development with maintenance of biodiversity. At the same time, it emphasises the importance of mixed species stands, as a main contributor to alpha and gamma diversity in ecosystem sustainability (Whittaker et al., 2001). Uneven-aged mixed species stands add a spatial dimension to diversity, exhibiting distinct hierarchies of horizontal and vertical structures (Getzin et al., 2006). These hierarchies are driven by inter-trees interactions, which are species-specific (Kobe et al., 1995; Getzin, 2006). As a result, the scientific community has dedicated significant efforts to quantify the relationships within uneven-aged mixed-species stands, particularly virgin forest.

Virgin forests are defined by the successional replacement of species, which depends on disturbance regimes and environmental heterogeneity (Getzin et al., 2008). During succession, the inter-trees competition balances two contrasting biological processes: attraction and repulsion (Stoyan and Penttinen, 2000). Attraction, which leads to aggregation and clumped patterns, is mainly caused by limited seed reproduction and dispersal; while repulsion, which leads to regular or uniform patterns, is a consequence of competition (Callaway and Walker, 1997).

Assessment of repulsion and attraction in mixed stands use parameters dependant methodologies (Kimmins et al., 1999; Illian et al., 2008; Bettinger et al., 2009a; Navarro-Cerrillo et al., 2013; Zhang et al., 2015). However, selection of parameters can alter the results significantly from both interpretation (Seppelt and Richter, 2005) and efficiency perspective (Liu et al., 2007;

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Bettinger et al., 2009b; Strimbu and Paun, 2012). Furthermore, complex investigations, such as multivariate or spatially explicit analyses, can be influenced by the metrics used in computations (Rencher, 2002; Hardle and Simar, 2003). Seppelt and Richter (2005) proved that even simple relationships can be interpreted differently, depending on selected methodology. However, in topics with rich knowledge, the impact of the methodology can be reduced, as contradictory results can be eliminated (Kosso, 2007). Nevertheless, for topic with limited knowledge, such as the spatial interaction between shade tolerant European beech (*Fagus sylvatica* L.) and shade intolerant sessile oak (*Quercus petraea* L.), the body of literature does not provide enough evidence to unequivocally support a particular finding (Stanescu, 1979; Pretzsch et al., 2013; Marçais and Desprez-Loustau, 2014; Ningre et al., 2016). According to Google Scholar more than 1000 research articles were dedicated on the mixture beech – sessile oak (Google Scholar, 2016), but less 100 were focused the spatial relationship between the two species, out of which approximately a dozen used methods based on second-order statistic (Pretzsch et al., 2013; Petritan et al., 2014), such as *K*-function or *O*-ring statistics. The advantage of using second –order statistics in analysing spatial relationships over other available approaches, such as geostatistics or lattice, consists in their focus on pattern identification. Furthermore, second-order statistics does not depend on additional parameters, such as Morisita's index, which make them more robust to analytical assumptions.

The *K* function cumulates the events or entities within a circle (Ripley, 1976); therefore, it cannot distinguish the effects occurring at smaller distances from the effects manifested at larger distances, the so called "memory effect" (Condit et al., 2000). An approach that identifies ecological processes occurring at a particular distance without including other distance, basically overcoming the memory effect, is the *O*-ring statistic (Wiegand and Moloney, 2004). The *O*-ring statistic, sometimes called *Palm intensity function* (Illian et al., 2008), is derived from the Ripley's *K* function, and depends not only on the diameter of the ring but also on the width of the ring. The ability of *O*-rings to detect relationships at specific location is therefore dependent on two parameters (i.e., inside radius and width), whose values can lead to different interpretations. Therefore, the objective of the present research is to assess the impact of parameters defining the *O*-ring methods on the interactions between European beech and sessile oak. This objective is of particular importance especially when literature supplies evidence of contradictory results. Some studies found that shade-tolerant beech and shade-intolerant sessile oak repulse one – another (Arévalo, 2013; Petritan et al., 2014) while other studies provide evidence of the opposite (De Luis et al., 2008; Fajardo and González, 2009). The hypothesis of the study, which is that *O*-rings parameters does not impact the analysis, tries to explain the contradictory findings through investigation of the mixed beech-sessile oak ecosystem. The hypothesis was tested using second – order statistics expressing competition, and computed for number and size (i.e., dbh, basal area, and volume) of individuals.

2. Methods

2.1. Study sites and data collection

The study was carried out in Runcu Grosi Reserve, located in the western part of Romania (46°11′N and 22°07′E), and contains a variety of mixed species stands that typically display old-growth traits (Petritan et al., 2012). The climate is classified as temperate continental, with average annual temperatures between 7.6 and 9.4 °C, and an average annual precipitation of 750–925 mm, approximately 60% of which occurs during the growing season. The hypothesis of the study was investigated using two square plots of 1 ha: one located on an approximately flat area at 500 m elevation, which is dominated by European beech (as % total volume), and one placed on a gentle slope (i.e., the elevation between 390 and 460 m), which is dominated by sessile oak (Table 1). All trees with diameter at breast height (dbh) $\geqslant$ 7 cm were stem-mapped using Field Map Data Collector (Institute of Forest Ecosystem Research, 2010), and each tree had species, dbh, total height, and vitality (dead/alive) recorded, similarly to Tabaku (1999) and Drößler and Lüpke (2005).

The plots are approximately similar in respect with relative frequency, beech being 82% in one plot (named henceforth "Beech dominated") and 63% in the other one (named henceforth "Sessile Oak dominated"). More than 95% of the beeches were alive in both plots, while sessile oak had more than 80% of the trees alive (Table 1). From size perspective (i.e., dbh and height) sessile oak had comparable values in both plots (i.e., dbh ~ 60 cm and height ~33 m), but beech was significantly larger in beech dominated plot than in the sessile oak dominated (i.e., dbh = 39 cm and dbh = 23 cm, respectively). The dbh and height difference between the plots for beech was further reflected in a pronounced volume difference. The volume of standing trees, approximately 820 $m^3\ ha^{-1}$ in the sessile oak dominated plot and 650 $m^3\ ha^{-1}$ in the beech dominated plot, is similar to other reported beech-oak mixed virgin forests, as Korpel (1995) found 705 $m^3\ ha^{-1}$ in the Slovakian forest Havesova, and Detsch (1999) determined 676 $m^3\ ha^{-1}$ in the German beech-sessile oak mixed reserve of Ludwigshain. The volume was calculated using the double logarithmic equation of Giurgiu and Draghiciu (2004).

The hypothesis of the study is tested using an approach based on *reductio ad absurdum* (Robles, 2008), which in many situations proves a statement by examples (Franklin and Daoud, 2011). The current hypothesis when *O*-rings are used in analysis is that width of the ring does not influence the results. Therefore, if an example is proven to the contrary, a proof by contradiction is obtained. In the case of *O*-rings, if width of the ring is found to alter the interpretation in just one situation, then the hypothesis is rejected. Consequently, there is no need for multiple plots or repeated measurements of the same ecosystem; two plots and one measure suffices if rejection of the hypothesis is attained.

2.2. Spatial analysis of the point patterns

The Ripley's $K(r)$ function (Ripley, 1977) is one of the most popular functions used in spatial point pattern analyses, and is defined as the ratio of the expected number of points describing a phenomenon of interest that are located at a distance of at most r from a random event and the intensity of the Poisson process associated with the phenomenon of interest (Cressie, 1993). An extension of the Ripley's $K(r)$ is the O-ring statistic $O_{12}(r)$, which measures the expected number of points having a particular pattern (called pattern 2) located at distance r from an arbitrary set of points having a different, or same pattern (called pattern 1). A further enhancement of the O-ring statistic is the pair-correlation function $g_{12}(r)$ (Condit et al., 2000; Getzin et al., 2006; Martínez et al., 2010; Luo et al., 2012), which measures the expected density of points with a specific pattern (i.e., pattern 2) in a ring of width Δr at a given distance, r, [i.e., $O_{12}(r)$] from an arbitrary set of points of a different, or same, pattern (i.e., pattern 1), divided by the intensity of the points having pattern 2 (i.e., λ_2) (Stoyan and Stoyan, 1994): $g_{12}(r) = O_{12}(r)/\lambda_2$. The pair-correlation function is deterministically related to the Ripley's K function by the differential equation (Stoyan and Stoyan, 1994):

$$g_{12}(r) = \frac{dK_{12}(r)}{dr}(2\pi r)^{-1} \tag{1}$$