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Spatial patterns of oak species in the Zagrosian forests of Iran

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Abstract

Spatial patterns of trees are important characteristics of forests to analyze canopy replacement, regeneration, forest dynamics and identify biological relationships between species. This study aims to investigate the spatial patterns of oak trees (*Quercus*) in natural deciduous forests in the Zagrosian region of western Iran. The study was performed in four 2-hectare plots in high-grade oak dominated stands including *Q. brantii* Lindl., *Q. infectoria* Oliv. and *Q. libani* Oliv. tree species. Records were taken for all trees in each plot for diameter at breast height, crown diameter and spatial coordinates. Spatial point patterns were analyzed using Ripley's *K*-function. Results showed that *Q. brantii*, which was the most dominant, or co-dominant species, exhibited clustered distribution in both pure and mixed stands. The spatial pattern of *Q. infectoria* was clustered in the mixed stands as dominant and co-dominant species. *Q. libani* showed clustered distribution in all distant scales (m); however, when mixed by *Q. infectoria* displayed random distribution as a co-dominant species. In general, results showed that *Q. brantii* which is a widespread tree species in Zagrosian forests of Iran, had effect on spatial distribution of the other oak species. The information derived from these stands could be useful as a key reference for developing management programs, silvicultural interventions, afforestation and reforestation programs as well as conserving and restoring of this forest endangered ecosystems.

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Introduction

Oak is a dominant tree species in various types of forest including temperate, subtropical and tropical as well as in some areas of chaparral and scrubland (Nixon, 1993). North America, Europe and Eastern Asia are the three main distribution centers of oak trees in the world and there are about 250 *Quercus* species in the Asia (Kyeung and Joong, 2000).

Iranian forests are divided into five regions and *Quercus* is a common genus growing in three of those regions including Alborz, Zagros and Arasbaran (Yazdian, 2000). The Zagros region is located in a semi-arid area (Fattahi, 1994) and is one of the main regions where several different oak species grow (Sagheb- Talebi *et al.* 2003). Forests in the Zagros region of western Iran (approximately 3 million ha.) include various oak species, which are mostly dominated by *Quercus brantii* Lindl., *Quercus infectoria* Oliv. and *Quercus libani* Oliv. (Fattahi, 1995).

Q. brantii has very wide-ranging distribution and is commonly mixed with *Q. infectoria* in the more favorable sites (Jazirehi and Ebrahimi Rostaghi, 2003). *Q. libani* can be found in the northern mountains above 1500 m.a.s.l. (Chapman, 1948). *Q. infectoria* prefers half shade or semi to full sun and grows in moist soil types; the species pervades in middle latitudes of Asia and is mainly located on northern slopes and domain soil (Fattahi, 1994; Maroofi, 2000; Mehdifar, 2005; Talebi *et al.* 2010).

The spatial pattern of a tree species has an important effect on the vitality of vegetation in an ecosystem (Callaway, 1992; Tilman and Kareiva, 1997; Nathan and Muller-Landau, 2000).

Spatial patterns of forest trees can be random, uniform, clustered or mixtures of these (Cressie, 1993). Analysis of spatial patterns for individual species provides important information for ecologists, because most ecological phenomena investigated by sampling in terms of geographic spaces are structured by forces that have spatial components. It is now understood that species distribution occurs from a combination of forces, some of which are external and the others are intrinsic to a particular community (Legendre and Legendre, 2003). Ecologists know from experience that as some processes such as reproduction, development and mortality all have important impacts, organisms are never distributed randomly or uniformly in an environment (Legendre and Legendre, 2003).

Competition is the main ecological factor affecting the dynamics, growth and survival of species (Peet and Christensen, 1987; Keddy, 2001; Szwagrzyk and Szewczyk, 2001). Tilman, (1994) believed that spatial structure is created by dynamics, competition and biodiversity of vegetation. Moreover, competition and interaction between species are two important factors influence on spatial patterns of trees (Frelich *et al.* 1993). Chen and Bradshaw, (1999) believed that species competition causes random patterns. Each individual tree in a forest environment constantly demands more crown and root space, which changes the structure and composition of a forest community. Intraspecific competition, competition between trees of a single species; does not affect the composition of a forest ecosystem and therefore has no direct effect on forest succession (Barnes *et al.* 1998). Interspecific competition, that is, competition among individuals of different species, however, results in a change of composition and structure of the stand (Barnes *et al.* 1998).

Despite of biological and environmental importance of Zagrosian forests, a few studies have been done on their spatial distributions in Iran: Basiri *et al.* (2006) determined the spatial patterns of the three oak species in northern Zagrosian forests as cluster using Green and Morisita's indexes. Heidari *et al.* (2007) used T- square method and Hopkins's index to determine the spatial patterns of *Q. brantii* in northern Zagros and found aggregated pattern. Erfani Fard *et al.* (2008) studied spatial patterns in the southern Zagros forests in a 30-ha plot using the Nearest Neighbor index and identified a dispersed spatial pattern. A clustered pattern was determined for *Q. brantii* in northern Zagros forests from the study of Safari *et al.* (2010) by fixed area plots and distance method. However, nobody used mapped data to detect the spatial patterns of different oak species in the Zagrosian forests of Iran using Ripley's *K* (*L*) function, so far.

Lookingbill and Zavala, (2000) believe that mapping plant distribution patterns is an important part of understanding a plant community's dynamics; hence, many studies have been done on different kind of forests all over the world, especially on oak trees distribution patterns (Mosandl & Kleinert, 1998; Kunstler *et al.* 2004; Liu *et al.* 2007; Hao *et al.* 2007; Longuetaud *et al.* 2008; Rozas *et al.* 2009; Wang *et al.* 2010).

The proper management of Zagrosian forests in Iran is essential, since the species that grow in these forests need to be managed for effective conservation and restoration to combat ongoing human disturbances and illegal exploitations in recent years. Therefore, the aim of this study is to investigate the spatial patterns of three oak species in the Zagrosian forests of Iran using the univariate Ripley's *K*-function for any close to nature intervention in managing forests and for sustainable management of forest ecosystems, as well.

Materials and methods

Study sites

In the basis of oak species distribution, Zagrosian forests of Iran are divided to two regions; northern and southern. The northern region is an exclusive site for *Q. infectoria* associated with one or both of *Q. libani* and *Q. brantii*. However, the southern region is an exclusive site for *Q. brantii*. The northern has a more humid and colder climate than the southern (Sagheb-Talebi *et al.* 2003).

This study was conducted in the forests of northern Zagros region. These forests are essentially sparse forests due to harsh environmental conditions and disposable to human disturbances i.e. cultivation under and among trees and cutting and exploitations of trees for animal husbandry and fuel, as well. We selected four sites in this region were located in areas with the least human intervention and without any management history as following (Fig. 1; Table 1):

1. Chenar forest, with two species of oaks: *Q. brantii* and *Q. infectoria*.
2. Heydariyeh forest, with one species of oaks: *Q. brantii*
3. Armardeh forest, with three species of oaks: *Q. brantii, Q. infectoria* and *Q. libani*
4. Sabadlou forest, with three species of oaks: *Q. brantii, Q. infectoria* and *Q. libani*

Data collection

In every site, we selected a 2-hectare (100 m × 200 m) sample plot on gentle slope, randomly. In total, four 2-hectare sample plots were established in the study sites in the summer of 2009. The slope orientation of all plots was in a cardinal direction (Dimov *et al.* 2005). In each plot, species and diameter at breast height (d.b.h. = 1.3 m above the ground) were recorded and mapped for each tree with a d.b.h. greater than 2.5 cm using slope-corrected distance and azimuth from a reference point (i.e., southwest corner of each plot). Records of distances and azimuths were then transformed to Cartesian coordinates.

Point processes and Ripley's K- function

A point process is the equivalent of a random variable whose result is a point, defined by its coordinates (x, y) in a pre-defined area (Goreaud *et al.* 1997). The point process formulation can be used to describe and analyze point patterns, especially by determining some global properties (laws) in random locations of trees in a stand (Goreaud *et al.* 1997). A point process is a stochastic process, which generates point patterns that share the same spatial structure (the law of the process), such as Poisson (completely random), regular, or clustered (Goreaud *et al.* 1997). A stand can be considered as a realization of an underlying point process, whose properties are a good description of the spatial structure of a stand (Goreaud *et al.* 1997). Several methods have been used in other researches to determine spatial patterns in forest stands, such as Greig-Smith (1952), Clark and Evans's index (1954), Morisita's index (1957) and Ripley's *K*- function. The last one defined by Ripley (1976, 1977), can be used to present a good indication of spatial structures (Besag, 1977, Diggle, 1983, Cressie, 1993). Therefore, a univariate version of Ripley's *K*-function was used in this study to determine the spatial patterns of all trees in the study sites.

Under the assumptions of stationary (the process must be invariant under translation) and isotropy (invariance under rotation), the main characteristics of a point process can be summarized by its intensity λ (the expected number of points per unit area) and Ripley's *K*-function, defined so that λ×*K(r)* is the expected number of neighbors in a circle of radius *r* centered on an arbitrary point of the process. As *r* increases, results include all information in the circle (Ripley, 1977). We can calculate estimators of λ and *K(r)* using equations 1 and 2 (Goreaud *et al.* 1997):

$$\hat{\lambda} = \frac{N}{S} \quad (1)$$

Where *N* is the number of points in the pattern and *S* is the area of the study region;

$$\hat{K}(r) = \frac{1}{\hat{\lambda}} \times \frac{1}{\hat{N}} \times \sum_{i=1}^{N} \sum_{j \neq i} Kv \quad (2)$$

Kv=1 if the distance between *j and I* is less than *r*, and 0 otherwise.

Line arise function *L(r)* was used to simplify interpretation (equation 3) as cited in Besag (1977):

$$\hat{L}(r) = \sqrt{\frac{\hat{K}(r)}{\pi}} - r \quad (3)$$

For a Poisson pattern, *L* (*r*) □□0 at every distance *r*; for clustered patterns at distance *r*, *L* (*r*) □□0; and in the case of regularity at distance *r*, *L* (*r*) □□0. For edge correction, Ripley's isotropic correction formula (Ohser 1983, Ripley 1988) was applied. Monte Carlo simulation was used to test the null hypothesis of random distributions. A 95% confidence envelope of $L(r)$ was computed with 999 simulated random patterns at 5% significance (P<0.05). If the values of $L(r)$ fell below, within or above the confidence envelope, then the observed spatial pattern was considered as regular, random and clustered, respectively. We calculated $L(r)$ at 5 m intervals over the range of distances from 0 to 50 m. The maximum distance of *r* =50 m is equal to one half the shortest side of the plot (Moeur 1993, Woodall and Graham 2004, Salas *et al.* 2006, Zhang *et al.* 2009) in each of the two hectare (100 m × 200 m) plots. The software package used for spatial analyses was Arc GIS version 9.2.

Results

Table 2 shows stand characteristics in the different sites. Stem number varied between 168.5 in Sabadlou and 289.5 per hectare in Chenar site. The least mean d.b.h. was calculated in Chenar (6.2 cm), while the highest was in Armardeh site (30.9 cm). Chenar site showed the minimum mean crown cover (5.9 m^2ha^{-1}), whereas Heydariyeh showed the maximum (14.9 m^2ha^{-1}) (Table 2).

Figure 2 shows the diameter distribution in the four study sites. All sites except to Chenar, show even-aged stand diameter distribution.

Figure 3 shows the spatial distribution of different oak species in the four study sites. In Chenar and Heydariyeh, *Q. brantii* was the dominant species, while in Armarde and Sabadlu, *Q. libani* and *Q. infectoria* were dominant species, respectively.

As seen in Figure 4, the spatial distribution in all studied sites is cluster.

Figure 5 shows the univariate Ripley's *K*- function results for the three oak species in the four study sites, individually.

Q. brantii as dominant or co-dominant species, in all pure (Fig. 5, A), and mixed stands (Fig. 5, B and C) shows a clustered pattern at all scales.

The spatial pattern of *Q. infectoria* as the dominant tree species (Fig. 5, D) in mixed stands and as co-dominant species (Fig. 5, E), is clustered (P<0.05) at all scales. However, its spatial pattern when mixed by *Q. brantii* is random up to 17 m and after that, the distribution is classified as cluster, except in a scale more than 45 m, which has again fallen in the random area (Fig. 5, F).

Q. libani as a dominant species displays cluster distribution in all scales (Fig. 5, G); however, when mixes by *Q. infectoria* as a co-dominant species, displays random distribution, totally (P<0.05) (Fig. 5, H).

Table 1. Characteristics of study sites.

Site name	Dominated species	Soil	Annual precipitation (mm)	Annual temperature (˚C)	Altitude (m)	Slope (%)	Center coordinates (UTM)
Armardeh	*Q. libani*	Loam- Clay to Loam	714	13.6	1670	30	573861; 3975874
Chenar	*Q. brantii*	Loam- Clay to Clay	458	14.2	1520	27	686277; 3760318
Heydariyeh	*Q. brantii*	Loam- Clay to Clay	492	13.6	1250	10	611095; 3773626
Sabadlou	*Q. infectoria*	Loam- Clay to Loam	714	13.6	1758	30	586052; 3988248

Table 2. Summary of some stand characteristics.

Site name	Density (trees ha^{-1})	Mean d.b.h. (cm)	Max d.b.h. (cm)	d.b.h. Coefficient of variation	Mean crown cover (m^2ha^{-1})
Armardeh	222.5	30.9	64	30.1%	7.40
Chenar	289.5	6.2	57	161.9%	5.9
Heydariyeh	182.0	18.6	70	46.7%	14.9
Sabadlou	168.5	24.2	52	30.4%	13.2

Discussion

Many factors including human activities, forest fires, physiographic conditions and mixtures of species affect strongly on spatial distribution of trees.

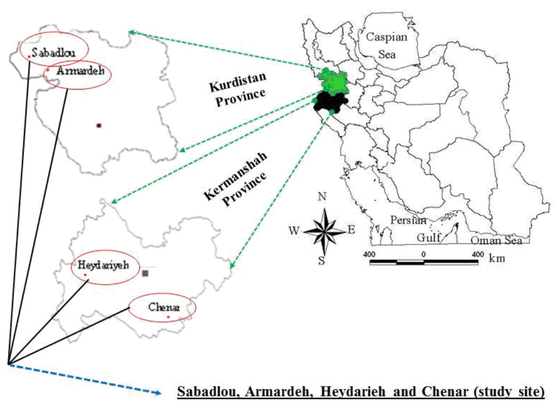

Fig. 1. Locations of study sites in the northern Zagros, Iran.

In this study, the spatial patterns of three oak species were analyzed in the least human intervened forest areas in the northern Zargros region of Iran. Spatial patterns of trees in the four study sites showed cluster distribution in both pure and mixed stands. At the same time, patterns observed for individual species, especially for dominant species was aggregated (Fig. 3; A, B, C, D, E and G), except to two co-dominant species; one in the Chenar site at very short and very high scales (Fig. 3, F) and the other one in the Sabadlou site at all scales (Fig. 3, H), which showed random distribution. In general, a clustered pattern is an indication of limited access to resources (light, water, nutrients) as well as harsh environmental conditions in the growing area that contributes to aggregation of plants in more favorable areas (Zhang *et al.* 2009). It is noteworthy that the Zagros forests have harsh conditions for growth due to low precipitation (mostly in autumn and winter), a dry summer climate and generally poor and shallow soil (Sagheb-Talebi *et al.* 2003). Furthermore, there are inherent limitations associated with the species such as seed dispersal (Akhavan *et al.* 2012); and *Quercus* is one of the genus with heavy seeds that produces an aggregated spatial pattern of juvenile oak trees.

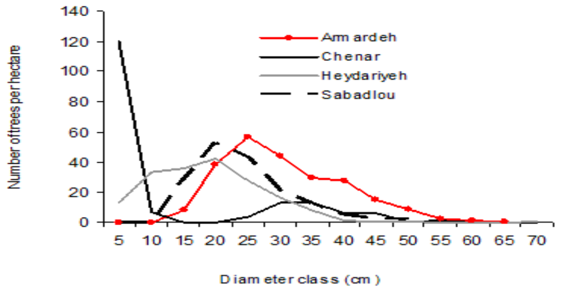

Fig. 2. Diameter distribution of trees in the four study sites.

Nevertheless, the main driver of aggregated spatial patterns for all trees in each site, as determined by Ripley's *K*-function, was the high aggregation pattern of dominant (based on frequency) tree species (Table 1; figure 2). Therefore, the role of dominant species (i.e. *Q. brantii*) in the configuration of whole stand spatial patterns is extremely important. For example, *Q. brantii* in every mixed stand with high abundance not only influenced on spatial patterns of *Q. infectoria* and *Q. libani*, but also influenced on the overall spatial pattern of trees at each site

Q. infectoria had random distribution in stands of heavily dominated by *Q. brantii*, while in stands without *Q. brantii,* there was significant clustered distribution of other species. *Q. libani* just in dominance had a clustered pattern, otherwise it showed random distribution. This alternation from significantly clumped to significantly random spatial distribution, explains inter-specific competition. It means that in competition for resources, dominant species do not allow to other species to establish and integrated, which confirms Chen and Bradshaw's theory (1999). However, other factors such as soil and topographic conditions may affect the spatial distribution of trees. Studies on oak stands in Spain showed that some ecological parameters including altitude, soil depth, mean annual temperature and some quantitative characteristics including mean diameter and mean height of trees are suitable for correctly defining the characteristics of oak stands (Blanco *et al.* 2000).

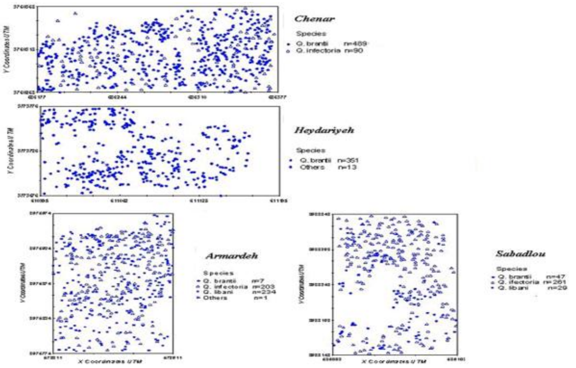

Fig. 3. Stem map of different tree species in the four study sites. n: number of trees for each species; other species including *Pyrus* sp. and *Crataegus* sp.

In this study, due to the wide ecological range and high flexibility of *Q. brantii*, other tree species were located randomly in special habitats. Study of Erfani Fard (2008) in the southern Zagros region of Iran showed dispersed distribution of *Q. brantii*; however, *Q. brantii* demonstrated clustered distribution in all sites in the northern Zagros (Basiri *et al.* 2006; Heidari *et al.* 2007; Safari *et al.* 2010).

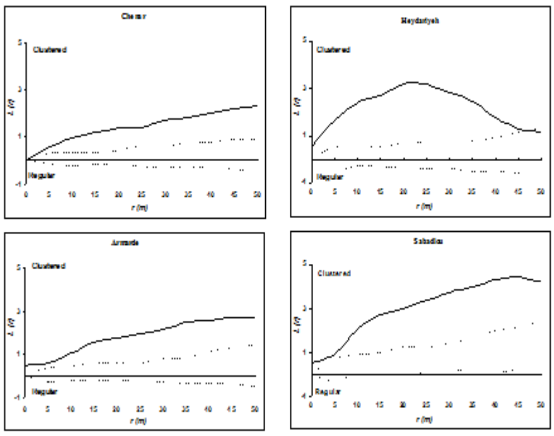

Fig. 4. Univariate results for the *L*-function for all tree species in the four study sites. Solid lines represent the *L*-function, dotted lines correspond to the 95% Monte Carlo intervals of the null hypothesis of complete spatial randomness. *L*-functions that fall above, below and within confidence intervals indicate cluster, regular and random spatial patterns, respectively.

The Zagros forests in western Iran are influenced by forest dwelling peoples, animal husbandry, agriculture and local people's fuel requirements; consequently, less intact areas can now be found in this region (Sagheb-Talebi *et al.* 2009). Therefore, knowledge about natural patterns of oak species is a key guide that can reveal the ecological characteristics of tree species to solve many problems in the management of such forested land in terms of solutions for sustainability such as reforestation and the rehabilitation of degraded areas.

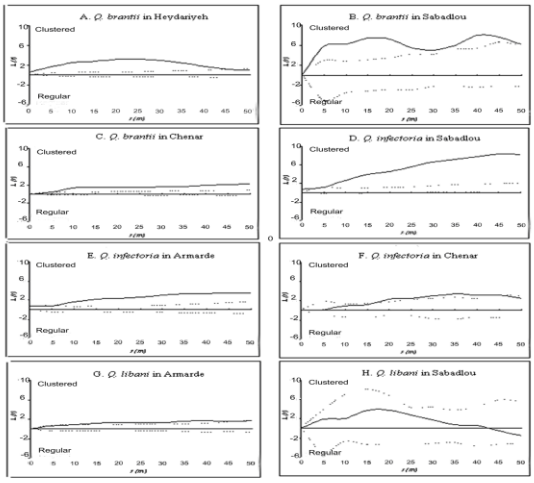

Fig. 5. Univariate results for the *L*-function based on oak species in each study sites. Explanations are the same as those for figure 4.

Furthermore, Information about spatial patterns may also be useful for improving growth models as well as giving us insight into competitive processes to enable better modeling of forest dynamics.

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