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# Spatial analysis of tree regeneration in a preserved area in Zagros forests, Iran

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## Abstract
Forest ecosystems are complex dynamical systems described by attributes of composition, structure, and function. To understand and manage forest ecosystems, we are required to explain and classify their dynamic structure and spatial patterns. We investigated the spatial patterns of trees and their regenerations in a preserved area in Zagros forests of western Iran. We applied geostatistical methods to examine the spatial pattern in distribution of tree and regeneration density and diversity. Fractal analysis was also used to characterize the complexity of the spatial patterns. The results showed that the mean of tree density per plot was 10.56 (S.E. ± 0.29) individual with canopy cover being 18.1 (S.E. ± 0.96) percent per plot. The mean of regeneration density was 3.06 (S.E. ± 0.23) individual in plot. We revealed spatially structured characteristics for tree density and diversity indices through the variograms that showed the presence of spatial autocorrelation. We also found that preservation favored density and diversity of tree regeneration in this area compared to unpreserved area. We also found that fractal dimension representing the unpredictability of spatial patterns, is high for trees and regeneration. This implies that although spatial dependence in semivariograms exists, it is generally fairly weak. These results revealed the scattered and homogeneous spatial distribution of trees and their regeneration in Zagros forests. It seems that the preservation action is not yet sufficient to effect on the spatial pattern of regeneration in this area. Therefore, conservation efforts must continue to complete the recovery of regenerated forest and flourishing of their spatial structure.

***Keywords***: Spatial ecology, Fractal dimension, Restoration, Semivariogram

## Introduction
Due to the importance of biodiversity in the sustainability of forest ecosystems and the services and resources they provide to human societies, the maintenance of biodiversity is regarded as a main aspect of the current forest management practices (Tiscar-Oliver, 2015). With increase in concern of the environmental, social and political sector over the loss of biodiversity, better understanding of issue has become crucial for conservation of ecosystems (Dufour et al., 2006)

Biodiversity is changing at an unparalleled rate: many species are diminishing in abundance, due to habitat destruction and pollution (Butchart et al., 2010) and there is increasing biotic homogenization across the globe (Pocock et al., 2015). These alterations have affected the human society by impacting on benefits we obtain from nature (Pocock et al., 2015). Despite intense conservation attempts and biodiversity monitoring, the currently available information is inadequate (Pereira et al., 2013) and knowledge about patterns of biodiversity are still scarce. Many current biodiversity studies emphasize invertebrates, birds and mammals (Ren et al., 2006), although studies on plant diversity can shed much light on biodiversity assessments (Pausas and Austin, 2001).

The species richness and diversity of trees are basic to total forest biodiversity, because trees provide resources and habitat for almost all other forest species (Malik, 2014). To understand the structure of a forest community and for planning relevant conservation strategies, we have to have

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quantitative information on composition, distribution and abundance of tree species (Singh et al., 2016).

Forest ecosystems are complex dynamical open systems that can be explained to some degree by their composition, structure, and function (Frazer et al., 2005). To understand and manage these complicated ecosystems, we have to describe and classify their complex and dynamic structural and spatial components (Nadkarni et al., 2008). The future composition and structure of the forests depends on the potential regenerative status of tree species within a forest stand. Regeneration of any species is bounded to specific habitat conditions and the extent of those conditions is a main element showing species distribution. When sufficient population of seedlings and adults are present in the structure of a forest, it normally indicates successful regeneration of forest species (Saha et al., 2016). Quantitative analysis of tree regeneration and diversity can offer baseline information for conservation and management strategies (Singh et al., 2016).

Disturbing of ecosystems changes the dynamic of species and ecosystem processes. Ecosystems are considered entities that move in a self-organizing way towards a more efficient use of energy/nutrients input. As a result of self-organizing, spatial patterns of vegetation at larger scales appear as patches going from homogeneous vegetation cover to periodic patterns, to scattered patches and finally to bare-ground. This self-organization attribute of the ecosystem is an inherent feature of non-linear interacting systems (Alados et al., 2005). Techniques used to study non-linear systems could be able to quantify the structure of complex spatial dynamics of plants. The mathematical features of spatially complex systems are often fractal (Jonckheerea et al., 2006). Fractal aspect has the potential to expose a new way to understand and analyze such natural spatial phenomena, which are not smooth, but rough and fragmented to self-similarity (Li, 2000).

Fractal analysis is a valuable tool for characterizing, measuring and comparing natural features and distribution of plants in ecology (Halley et al., 2004; Jonckheerea et al., 2006). To gain a good understanding of spatial complexity and species distributions pattern and diversity extinction thresholds, many recent spatially-explicit studies have applied fractal analysis (Palmer, 1988; Loehle et al., 1996; Li, 2000; Despland, 2003; Alados et al., 2003, 2005; Jonckheere et al., 2006; Halley et al., 2004).

Because of the long history of intensive human control on many semi-arid Mediterranean forests through cropping, grazing, burning and deforestation, these ecosystems have been affected for centuries and as a result adapted and evolved to these pressures. In ecosystems such as semi-arid Mediterranean ecosystems with considerable drought periods and with high alteration of abiotic conditions, adaptation is seen in the structure and perhaps function (Alados et al., 2005). However, disturbances are important natural drivers of forest ecosystem dynamics (Kuuluvainen and Aakala, 2011), and strongly modify the structure and functioning of forest ecosystems. Disturbance can thus noticeably change forest ecosystems, with irreversible impacts on their diversity and capacity to provide ecosystem services (Thom and Seidl, 2016). These changes can be quantified by the fractal dimension of vegetation spatial patterns, which indicate important changes in ecosystem structure (Alados et al., 2003).

In this study we have investigated the spatial pattern of trees and their regenerations in Zagros Oak forests. Similar to other semi-arid forests around the world, in recent decades the Zagros forests in western Iran have undergone dramatic changes in cover, regeneration and structure. The rapid decrease in forest area in Zagros, suggests the possibility of similar dynamics behind grave alterations that have been found in other semi-arid areas of the world (Henareh Khalyani et al., 2013). Additionally, in Zagros forests with degraded soils and limited nutrient and humidity, disturbance may easily lead to loss of important species in the absence of an alternative community that can replace this well specialized flora. Based on the national and regional importance of Zagros forests, it is highly beneficial for restoration management to identify important changes in forest regeneration, and to evaluate spatial patterns, which might signal imminent changes. In order to prevent irreversible decadence, we need appropriate tools that enables us to detect the changes in the ecosystem dynamic and spatial structure (Alados et al., 2005) which is essential to understand, manage and conserve forests (Nadkarni et al., 2008). Therefore, this study evaluated the spatial patterns of trees and their regeneration in Gahvareh forest of the western Iran which has been preserved for 11 years using geostatistics and fractal analyses. The objective of the study was to examine the spatial patterns of trees and their regeneration after a period of 11 years of preservation, and to determine if this duration of preservation has been sufficient for recovery of regeneration and its spatial distribution.

## Material and Methods

### *Study area*

The study was conducted at the Gahvareh forests of the western Iran (34$^{o}$ 27$^{/}$ 23$^{/\,/}$ - 34$^{o}$29$^{/}$ 19$^{//}$ N and 46$^{o}$36$^{/}$ 87$^{/\,/}$- 46$^{o}$ 39$^{/}$07$^{/\,/}$E) (Figure 1). Average annual rainfall is 490 to 550 mm with mean temperature of 11 to 13°C. The forest is dominated by oak (*Quercus brantii* Lindl) but a mix of up to 6 tree species are found with changing composition. This area has been preserved by Forest, Rangeland and Watershed Management Organization of Iran from 2006 to establish and enhance forest regeneration. It should be mentioned that preservation has become even more necessary as a result of loss of regeneration in Zagros forests. Following intensive human domination, grazing and deforestation in these forests, signs of regeneration are normally not seen in these precious ecosystems.

### *Sampling procedure*

To examine spatial pattern of trees and their regeneration, we used data collected from a systematic sampling grid of 400 m$^2$ (20 m× 20 m) plots. The initial installation consisted of 25 plots on 200 m spacing (100 ha). Sampling was densified in one fourth of the initial grid by installing 25 plots, which reduced the spacing between plots to 50 m. Totally, 50 plots were sampled. The starting point was chosen randomly in an area with a northwest-facing aspect.

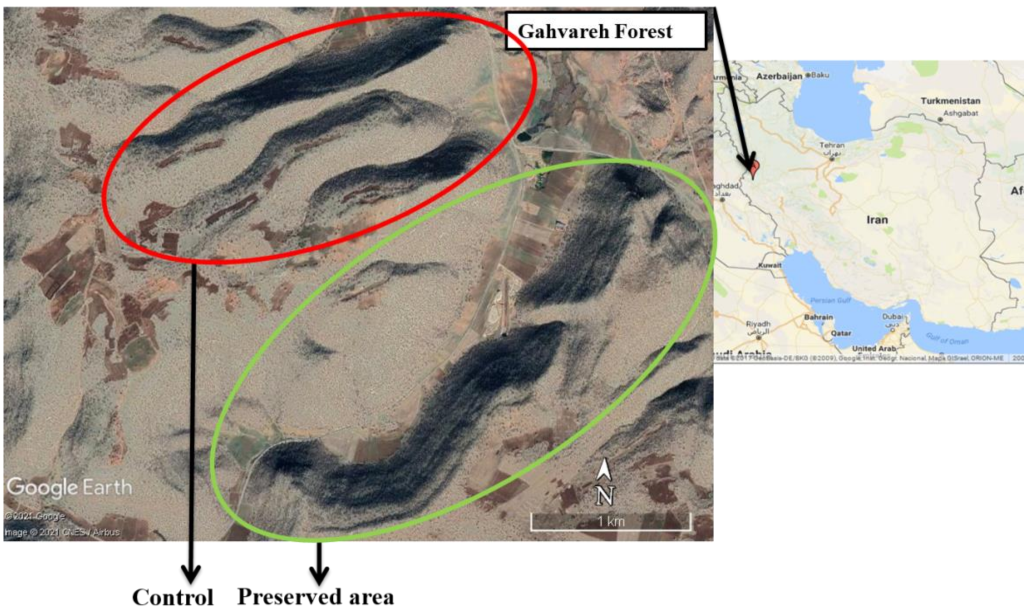


**Figure 1.** Study area

We counted tree species (Cesarz et al., 2007) and measured canopy cover and tree density in each plot. In each plot, tree regeneration (number of individuals of each tree species with height < 1.30 m) (Tiscar-Oliver, 2015) was also counted. This sampling procedure (50 plots (20 m× 20 m)) was also conducted in an unpreserved area only for studying the regeneration. This area was selected two kilometers away from the preserved area as control (Figure 1).

***Statistical approach and methods***

Three useful indicators of spatial patterns including evenness (Sheldon index), richness (Menhinick index) and diversity (Shannon $H^{/}$ index) were calculated in each plot for trees and their regeneration (Cesarz et al., 2007) using PAST software version 1.39.

The distribution of variables was analyzed with Q–Q plots (Timmer, 1998). All variables (except tree density and regeneration evenness) were log normally distributed; therefore we applied a log-transformation (log (x + 1)) before further analysis. We applied geostatistics methods to examine spatial structure in distribution of tree species and regeneration diversity indices and canopy cover.

Several methods exists with which we can analyze and describe spatial pattern of patchy systems. Spatial statistics or geostatistics are necessary to document spatial autocorrelation. To study spatial complexity, however, geostatistical methods have severe limitations. For many types of non-stationary, and discontinuous patchy data, geostatistical methods do not account for these features of patchy landscape, neither they do allow researchers to distinguish or explain multi-scale structures. Thus, a new method is required to describe heterogeneity structures and patterns. Indeed, most phenomena show patterns midway between complete spatial independence and complete spatial dependence (Li, 2000).

Fractal analysis offers a methodology for assessing pattern structure across a range of scales; it provides a scale-independent measure of movement (With, 1994). Fractals provide a simple, effective way to measure complex forms, and they do so in a way that reflects structure and function (Jonckheerea et al., 2006). The fractal dimension (D) indices relates to the total complexity of the pattern (With, 1994) and provides a measure of the degree of correlation between patches over space (Li, 2000). There are different ways to measure the fractal dimension of objects and processes of which geostatistical tools can be used for portraying fractal correlations of patchy systems (Li, 2000).

***Geostatistics and Fractal Dimension***

Geostatistics is a branch of statistics that provide a means for characterizing and predicting spatially explicit data (Goovaerts, 1999). Semivariance modeling which is a commonly used method, includes calculating the variance for a pair of observations of a variable as a function of their separation distance. Formulating for multiple pairs at various distance classes (or lags) shows the quantity of spatial correlation of a variable across the sampled area (Fry and Stephens, 2010). The semivariance ($\gamma(h)$) graphically describes the spatial variability of a variable by plotting semivariance as a function of lag distance classes h (Equation 1):

$$\gamma(h) = {}^{1}/_{2N(h)} \sum_{i=1}^{N(h)} [Z(X_i) - Z(X_i + h)]^2 \qquad (1)$$

where z is the measured variable, $x_i$ is the coordinate of one sample, $x_i$ + h is the coordinate of another sample at distance (lag) h and N (h) is the number of pairs of samples z ($x_i$) and z ($x_i$ + h). The semivariance basically shows the average variance of pairs of points at a given distance.

The fractal dimension (D) of the graph of Z as a function of position along transect can be calculated from the slope m of the double logarithmic plot of the semivariogram using Equation 2 (Burrough 1983):

$$D = \frac{(4-m)}{2} \qquad (2)$$

If Z is a linear function of distance, the semivariogram will be of parabola shape. This is because the difference inside the parentheses in semivariogram equation is a linear function of h, and a linear function square is parabola. The slope of the double logarithmic plot of a parabola is 2, which corresponds to a fractal dimension of 1. If the values for Z in two near samples are no more or less different than in two distant samples, the slope of the semivariogram will be 0, corresponding to a fractal dimension of 2. Thus, the fractal dimension is an index of the degree of spatial dependence of a variable (Palmer, 1988).

## Results

### *Density and diversity of trees and regeneration*

Since there was not any regeneration in the unpreserved area, only the data of preserved area have been reported. Totally, tree species comprised of *Quercus brantii* Lindl, *Crataegus pontica* C.koch and *Ceracus microcarpa* (C.A.M) Boiss. The mean of tree density was 10.56 (S.E. ± 0.29) individual in each plot with canopy cover of 18.1 (S.E. ± 0.96) percent (Table 1). The mean regeneration density was 3.06 (S.E. ± 0.23) individual in each plot. As expected, tree species richness (0.51±0.03), diversity (0.23±0.03) and evenness (0.84±0.02) were lower than regeneration richness (0.87±0.07), diversity (0.44±0.06) and evenness (0.91±0.03) (Table 1). Tree regeneration mainly comprised of *Ceracus microcarpa* (C.A.M) (2.02±0.17), *Quercus brantii* Lindl (0.54±0.10) and *Crataegus pontica* C.koch Boiss and was 0.5±0.1 individual per plot (Table 1). Regeneration of *Ceracus microcarpa* was more abundant.

**Table 1.** Summary statistics of tree diversity, regeneration diversity and canopy cover

| Variable | Mean | Std. Error |
|---|---|---|
| Tree density (individual/plot) | 10.56 | 0.29 |
| Tree diversity | 0.23 | 0.03 |
| Tree richness | 0.51 | 0.03 |
| Tree evenness | 0.84 | 0.02 |
| Regeneration density (individual/plot) | 3.06 | 0.23 |
| Regeneration diversity | 0.44 | 0.06 |
| Regeneration richness | 0.87 | 0.07 |
| Regeneration evenness | 0.91 | 0.03 |
| Regeneration density of *Ceracus microcarpa* (individual/plot) | 2.02 | 0.17 |
| Regeneration density of *Quercus brantii* (individual/plot) | 0.54 | 0.10 |
| Regeneration density of *Crataegus pontica* (individual/plot) | 0.50 | 0.10 |
| Canopy cover (percent/plot ) | 18.1 | 0.96 |

Density: Number of trees/regeneration in plot; Evenness: Sheldon index; Richness: Menhinick index; Diversity: Shannon $H^{/}$ index.

### Spatial structure of trees and regeneration

#### *Variogram*

Tree density and diversity indices were spatially structured: the variograms revealed the presence of spatial autocorrelation. Spatial dependence for tree diversity and richness occurred at the distances of 2110 m, whereas tree evenness had spatial autocorrelation at the distance of 1769 m. Tree density had spatial dependency at the small distance of 57 m. The variograms of tree density and evenness were spherical, but tree diversity and richness showed an exponential pattern (Table 2).

Regeneration density and evenness were spatially structured as well with ranges of 4110 m and 490 m, respectively. Regeneration density of *Ceracus microcarpa, Quercus brantii and Crataegus pontica* had spatial dependency at the ranges of 330 m, 4110 m and 1983 m, respectively. The parameters of the theoretical models fitted to the experimental variograms are given in Table 2. Regeneration density showed an exponential model but evenness had spherical model. Regeneration diversity and richness did not show spatial dependency. The result showed small ranges for canopy cover at the distance of 98 m. Empirical semivariograms and the fitted models of variables are presented in Figure 2.

**Table 2**. Parameters of the theoretical models fitted to the experimental variograms of tree and regeneration properties

| Variable | Model | Nugget(Co) | Sill(Co+C) | Range(m) | $R^2$ | $R^2$ of cross-validation |
|---|---|---|---|---|---|---|
| Tree density | Exponential | 0.01 | 5.27 | 57 | 0.69 | 0.13 |
| Tree richness | Exponential | 0.02 | 0.04 | 2110 | 0.11 | 0.05 |
| Tree evenness | Spherical | 0.00 | 0.01 | 1769 | 0.51 | 0.12 |
| Tree diversity | Exponential | 0.03 | 0.06 | 2110 | 0.28 | 0.19 |
| Canopy cover | Spherical | 0.02 | 0.08 | 98 | 0.01 | 0.00 |
| Regeneration density | Exponential | 0.21 | 0.42 | 4110 | 0.24 | 0.02 |
| *Ceracus microcarpa* * | Spherical | 0.29 | 1.70 | 330 | 0.63 | 0.24 |
| *Quercus brantii* * | Exponential | 0.37 | 0.83 | 4110 | 0.6 | 0.02 |
| *Crataegus pontica* * | Exponential | 0.21 | 0.87 | 1983 | 0.95 | 0.13 |
| Regeneration evenness | Spherical | 0.00 | 0.00 | 490 | 0.75 | 0.01 |
| Regeneration richness ** | Linear | - | - | - | - | - |
| Regeneration diversity ** | Linear | - | - | - | - | - |

Co: nugget variance: the variogram values at lag distance zero. Sill: the variance at which the variogram model reaches a maximum; C: structural variance; Range: the lag distance at which the bounded variogram reaches the sill; $R^2$: goodness of fit of theoretical model fitted to the experimental variogram; $R^2$ of cross-validation: regression coefficient. Density: Number of trees/regeneration in plot, Evenness: Sheldon index; Richness: Menhinick index; Diversity: Shannon H$^/$ index. *: Regeneration density of *Ceracus mocrocarpa, Quercus brantii and Crataegus pontica ;* **Horizontal line; pure nugget effect indicating no spatial structure detected.

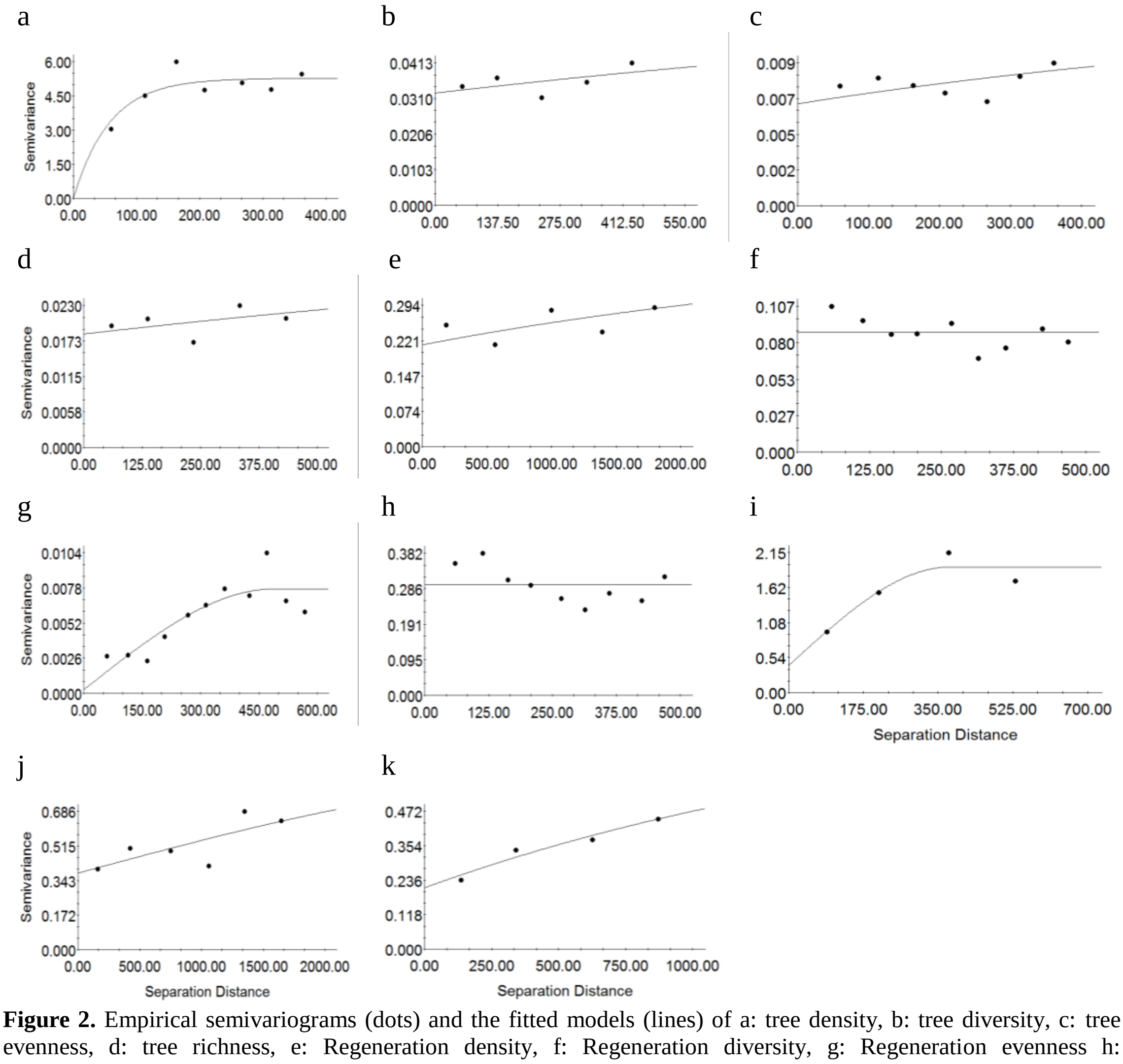


**Figure 2.** Empirical semivariograms (dots) and the fitted models (lines) of a: tree density, b: tree diversity, c: tree evenness, d: tree richness, e: Regeneration density, f: Regeneration diversity, g: Regeneration evenness h: Regeneration richness, i: Regeneration density of *Ceracus microcarpa*, j: Regeneration density of *Quercus brantii*, k: Regeneration density of *Crataegus pontica*. Density: Number of tree species/regeneration in plot, Evenness: Sheldon index; Richness: Menhinick index; Diversity: Shannon H$^/$ index.

***Fractal Dimension (FD)***

In most cases presented in Table 3, the fractal dimension was closer to 2 than 1. Tree diversity, richness, and regeneration density showed higher FD (1.98) and appeared to have complete homogeneity (remaining similar upon subdivision) over a wide range of spatial scales. Regeneration evenness had the lowest FD (1.7). Regeneration density of *Ceracus microcarpa* had also low fractal dimension (1.82) than the regeneration of the other two tree species. Therefore, across most of the scales we studied, communities were found to be almost homogenous. Regeneration diversity indices had lower fractal dimension than tree diversity (Table 3).

**Table 3.** Fractal dimension of tree and regeneration properties

| Variables | FD |
|---|---|
| Tree density | 1.87 |
| Tree diversity | 1.98 |
| Tree richness | 1.98 |
| Tree evenness | 1.95 |
| Canopy cover | 1.93 |
| Regeneration density | 1.98 |
| Regeneration density of *Ceracus microcarpa* | 1.82 |
| Regeneration density of *Quercus brantii* | 1.91 |
| Regeneration density of *Crataegus pontica* | 1.85 |
| Regeneration diversity | 1.95 |
| Regeneration richness | 1.88 |
| Regeneration evenness | 1.70 |

FD: fractal dimension

## Discussion

Spatial pattern as a component of forest structure plays a key role in the interspecies interactions (Ngo Bieng et al., 2013) and may disclose information about the historical and environmental processes such as regeneration, biodiversity, and competition. This knowledge facilitates the development of conservation plans and management strategies for forest ecosystems (Boyden et al., 2005).

In this study, we investigated the spatial pattern of trees and regeneration in a preserved forest in Zagros Oak forests of western Iran. The results showed a regeneration after 11 years of preservation in this region compared to the unprotected area. Totally, density and diversity of tree species and regeneration was low. Zagros forests are composed of sparse oak forests with open canopy which have experienced a long history of disturbances and habitat fragmentation (Henareh Khalyani et al., 2013). This region is characterized by hot and dry summers and low annual precipitation that limit trees growth and regeneration. Also climate appears to have had a major influence, historically and more currently, on the regeneration of this ecosysten. However, for successful germination of seedling we generally require good supply of seed, a mineral seedbed, sufficient moisture, and light (Boyden et al., 2005) which are the main limited factors in the study area. On the other hand, management method, habitat connectivity, and present species can directly or indirectly change species richness (Saha et al., 2016). Also, Pausas and Austin (2001) suggested that patterns of plant diversity is related to resource availability and factors that affect plant physiology.

Our finding showed that regeneration evenness and tree density spatially autocorrelated at the small distances. The small scale pattern (57 m) of tree density distribution found in our study could be the result of the individual plants interactions that generally occur on a finer spatial scale, e.g., the extent to which individual canopy and/or root systems develop (Torimaru, 2013). Although tree density distribution appeared to be aggregated, diversity, richness and evenness of trees and regeneration density of *Quercus brantii* and *Crataegus pontica* showed a large and smoothly continuous pattern probably as a function of large scale gradients of soil texture and topography. In forest communities, abiotic environmental factors such as topography and the relevant moisture and light conditions typically fluctuate over relatively large scales. In this context, species-specific preferences to such heterogeneous environments and their regeneration pattern influence the organization of the whole communities (Torimaru, 2013).

However, the semivariograms reveal the extent of variation in a variable as a function of scale. In most cases in our results, spatial autocorrelation was weak and occurred at large scales. An important related concept to spatial autocorrelation in ecology is that of distance decline of similarity. Similarity of species composition in communities of fauna and flora declines with distance and this can be linked to decrease in environmental similarity with distance (Kent et al., 2006). To study spatial dynamics and heterogeneity, however, present geostatistical methods have severe limitations (Li, 2000).

Hence, patterns of trees and regeneration were also analyzed by the fractal dimension. In most of the cases in our study, the fractal dimension was high. Fractal dimension is a good indicator for characterizing the heterogeneity of the system and offers a quantitative value for the degree of patchiness in the plant community independent of scale which increases with randomness (lack of spatial autocorrelation) (Alados et al., 2003, 2005). On the other hand, the sequence graphs of variables illustrated that tree and regeneration diversity indices had weak spatial dependency and were noisy at all scales, making the variograms horizontal. In the latter cases, we can infer that large scale spatial independence and small scale variation exist between data. However, it implies that although semivariograms exposed spatial dependence, it was generally fairly weak. Therefore, across this area, tree and regeneration density and diversity indices are almost homogenous. This homogeneity may be a result of white noise in the environment, vegetation, sampling error or combination thereof (Andronache et al., 2019). A system with white noise, in other words, complete noise has full spatial independence (Palmer, 1988).

According to our results, regeneration density of *Quercus brantii* had more fractal dimension than the regeneration density of *Crataegus pontica and Ceracus microcarpa.* Furthermore, the results indicated that the regeneration density of *Quercus brantii* was lower than *Ceracus microcarpa*. In any case, even as the conservative efforts indicate regeneration of tree species in this preserved area compared to the the unprotected area; regeneration of *Quercus brantii* as the most important tree species in Zagros forests is lower than those of the other species. Also, the spatial patterns reveal a shift in trees and their regeneration especially for *Quercus brantii* to a more scattered and unpredicted spatial distribution. This highlights that many ecological processes in this area act out upon a fractal stage (Halley et al., 2004; Rietkerk et al., 2002; Guzman et al., 2020).

## Conclusions

Our findings highlighted that spatial autocorrelation of trees in Zagros oak forests and their regeneration was weak while in most cases the fractal dimension was high. Fractal dimension accurately reflected the transition shift in spatial distribution of vegetation and provided a good analytical framework for understanding ecological complexity and dynamics of tree populations (Alados et al., 2005). Although preservation had effects on the recovery of trees and their regeneration density and diversity in the preserved areas compared to the unprotected areas, the spatial structures were found to be shifting to a more scattered and unpredicted spatial distribution, especially for the regeneration density of *Quercus brantii* as the most important and dominant tree species that shape the structure of these forests in western Iran. It seems that the preservation of the area for over 11 years has not been sufficient to affect the spatial pattern of regeneration and help trees establish successfully in this region. Therefore, conservation efforts must continue to complete the recovery process of destroyed forests and tree regeneration and their relevant spatial structure. As forest preservation goes forward in this region, the associated monitoring system and protection efforts need to be expanded in response to increase of ecosystem stresses in a bid to provide a more robust conservation framework in response to climate change in this area.

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**Conflict of interest**
The authors declare that they have no conflict of interest.

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