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Structure analysis of non-protected forest stands in Boyer-Ahmad County

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Abstract
Quantitative descriptions of forest structure are recognized as one of the most effective tools in modern forest management. As such, obtaining accurate and comprehensive information about the structure of tree species is crucial for the sustainable management of forest ecosystems. This study, conducted as part of a comprehensive monitoring plan for the Zagros forests using place-based monitoring, evaluates the structure of two forest stands: Sarabtaveh on the northern slope and Parikadan on the southern slope in the forests of Boyer-Ahmad County, Kohgiluyeh and Boyer-Ahmad Province. In each stand, a one-hectare square sample plot was randomly established, and quantitative variables related to tree stems were measured. The findings revealed that the dominant tree form in both stands was coppice or branch-derived. The spatial distribution pattern of the dominant species, Persian oak, was clumped in both regions. The mingling index was calculated as 0.23 for Parikadan and 0.14 for Sarabtaveh, indicating higher species diversity in Parikadan compared to Sarabtaveh. However, the mingling index for both regions (study areas) was relatively low, which aligns with the fact that Persian oak is the predominant species in the studied areas. The Clark-Evans index was 0.61 for Parikadan and 1.13 for Sarabtaveh. The diameter differentiation index was 0.33 for Parikadan and 0.32 for Sarabtaveh, suggesting no significant difference in the average diameter at breast height (DBH) and highlighting the homogeneity of trees in terms of diameter. Additional measurements and calculations included the uniform angle index, diameter dominance indices, canopy cover, neighborhood distance index, and structural diversity index, among others. The results of these indices provide a valuable foundation for comparing the studied forests with other similar ecosystems and identifying deviations caused by natural processes and human activities. Such comparisons will contribute to the development of effective management models and appropriate forestry methods tailored to the region's forests.

Keywords: Forestry, Mingling, Oak, Parikadan, Uniform Angle.

1. Introduction
In forest management, examining the structure of forest stands is essential for assessing current conditions and designing future plans (Pourhashemi et al., 2015; Henareh et al., 2024). Forest stand structures evolve over time due to local disturbances, a process referred to as forest stand dynamics (Sefidi et al., 2014). Vegetation cover characteristics are typically described using parameters such as leaf area index, stem count, dimensions, and cross-sectional area (Schultz, 2002). Forest structure focuses on the distribution of various tree characteristics within forest ecosystems (Gadow et al., 2012). It is closely linked to the habitats of numerous plant and animal species, making it a key component in describing forest ecosystems and biodiversity (Knit et al., 2005).

One of the key challenges in forest planning and implementation in the Zagros forests is the lack of awareness and detailed information about the natural condition and structure of forest stands. Without sufficient data on forest structure, achieving the long-term preservation of forest ecosystems becomes unlikely (Henareh et al., 2024). Researchers have proposed various

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factors for examining the structure of forest stands. Some foresters believe that stand structure should primarily be based on diameter class distribution and canopy cover, while others argue that it should encompass a broader range of attributes, including form, composition, stratification, diameter class distribution, and other biometric indices (Moradi et al., 2021; Zafarian Rigaki et al., 2023). Spatial diversity of trees pertains to their distribution pattern, which can be clumped, random, regular, or intermediate. Species diversity focuses on the spatial positioning of different species in relation to neighboring trees. Dimensional diversity, on the other hand, involves the spatial arrangement of characteristics such as diameter at breast height (DBH) and tree height (Pommerening, 2006).

In previous studies, researchers have examined forest structure based on three key characteristics. The first characteristic pertains to the spatial position of trees, describing whether their distribution pattern is regular, random, clumped, or intermediate. The second characteristic, species mingling, reflects species diversity. Lastly, dimensional diversity refers to the spatial arrangement of attributes such as tree diameter and height (Pommerening & Stoyan, 2006; Knit et al., 2000). In forest ecosystems, the term structure refers to the spatial arrangement of tree characteristics, including age, dimensions, species, and growth form (in dioecious trees) (Graz, 2004). Numerous statistical indices have been developed to quantitatively describe spatial structure. Among these are nearest neighbor indices, which operate similarly to chemical molecular structures by analyzing the neighbors of each tree or specific point within a forest stand (Pommerening, 2006).

Understanding forest structure is crucial for making informed decisions in forest management activities, including silvicultural and harvesting operations. Since 1992, the Forest Management Institute of the University of Göttingen in Germany has developed a set of indices based on nearest-neighbor methods (Corral et al., 2010). In recent decades, a significant number of structural indices have been introduced and used to quantify forest structure and biodiversity (Pommerening, 2002). In one study, the advantages of these indices were highlighted, including the lack of need to record tree positions and measure distances between them, and it was stated that forest structure assessment using these indices is more comprehensive and easier than traditional methods (Aguirre et al., 2003). These indices examine the distribution pattern of trees, the quantity and degree of dispersion of different tree species, and the dimensional status of trees, and by averaging them at the forest stand level, they describe various structural aspects (Wang et al., 2016). These indices have gained attention among researchers due to their ease of measurement, low cost, and high accuracy (Wang et al., 2016; Knit et al., 2000).

In Iran, these indices have also been used in several studies. In one study, the structure of tree species in beech, beech-hornbeam, hornbeam-beech, and hornbeam-oak forest types in the Hyrcanian forests was examined using 239 systematically and randomly established 1000-m² sample plots in Mazandaran Province, Iran, using Crancod software. The results of the uniform angle index indicated a random spatial distribution of trees in the four forest types examined (Alijani et al., 2012). The mingling index results also showed low mingling in the four forest types examined (Alijani et al., 2012). Comparison of the structure of similar species in different forest types showed no significant differences in spatial position, DBH, and height characteristics, and the only differences observed were in the mingling of hornbeam, beech, maple, and linden species (Alijani et al., 2012).

In another study, the spatial position, mingling, and dimensions of hawthorn and wild pear species relative to neighboring trees in the customary forests of Lorestan Province were examined. The results of the uniform angle index indicated a clumped arrangement of the two species relative to neighboring trees (Pilehvar et al., 2015). In terms of mingling, hawthorn and wild pear showed high species mingling. Additionally, the quantification of the spatial structure of juniper stands in the Kandaragh region (Ardabil Province) was examined. According to the findings, juniper in its natural habitat tends to be fairly pure in species composition and to have slightly heterogeneous diameter distributions and uniform tree height. Accordingly, maintaining the natural structure and spatial pattern of trees should be sufficiently considered in decision-making and planning strategies (Sefidi et al., 2018). The average values of the two-dimensional differentiation and dominance indices showed that hawthorn had high differentiation and was subordinate to its neighbors, while wild pear had moderate differentiation and was dominant over its neighbors (Pilehvar et al., 2015).

Recent studies have also examined the structure of two oak stands in Kermanshah Province. The results showed that the forest structure in the studied areas had changed significantly (Rahimi et al., 2023). Foreign researchers have likewise confirmed the usefulness of nearest neighbor-based indices in forest structure assessment. For example, one study examined the effect of species mingling on the structural diversity of Serbian spruce and Macedonian pine in remnant forest communities of the Balkan Peninsula. According to the results, the distribution pattern in stands with very high mingling was regular or uniform for individual trees, whereas in stands with lower mingling, the distribution pattern was clumped (Popovic et al., 2021).

This study represents the initial phase of a comprehensive place-based monitoring program for the Zagros forests, focusing on the structural assessment of two unprotected forest stands in Boyer-Ahmad County, Kohgiluyeh and Boyer-Ahmad Province: Sarabtaveh (north-facing slope) and Parikadan (south-facing slope). The current findings establish baseline data on stand structure and spatial distribution patterns, while subsequent monitoring phases will track temporal dynamics.

2. Materials and Methods

2.1. Study Area

Drawing on existing knowledge and resources concerning the structure of Zagros forests, a one-hectare (100 × 100 m) permanent square sample plot was randomly established in each of the two study areas (Figure 1).

Figure 1. Some of study areas sampled in Parikadan (left) and Sarabtaveh (right)

Then, structural variables of all trees within the sample plots were measured separately for high-forest and coppice growth forms (Table 1). For high-forest trees, species, spatial coordinates, diameter at 0.5 m height, DBH, and height were measured. For coppice bases, in addition to the above variables, the number of shoots in each coppice group, dominant height of the coppice group (height of the tallest shoot in each coppice group), and diameter at 0.5 m height of all shoots taller than 1.3 m within each coppice group were measured. Using these measurements, other structural variables such as crown area, density (canopy cover), stand density (number per hectare and basal area), coppice group diameter, and diameter and height distribution were calculated (Askari et al., 2024). Given the importance of the crown in the structure of Zagros forests, crown variables including large and small crown diameters and crown length were also measured.

2.2. Examined Indices

In this study, the uniform angle index and mingling index were employed to quantify spatial diversity and species mingling, respectively. DBH and height differentiation indices were used to measure diameter and height diversity. Furthermore, the nearest neighbor distance index was applied to analyze tree density within each sample plot. Table 2 provides a concise explanation of each of these indices.

Table 1. Characteristics of the studied areas

Region Name	Stand Conditions				Vegetation Type	Geographical Coordinates	
	Canopy Cover (%)	Average Altitude (m)	Geographical Direction	Average Slope (%)		Y	X
Parikadan	80	2045	South	38	*Quercus-Amygdalus*	3377953	558917
Sarabtaveh	50	1890	North	23	*Quercus brantii*	3382030	555618

Table 2. Description of Nearest Neighbor-Based Structural Indices

Index	Description	Equations	Index name	Reference
Spatial Pattern	$E(r) = \frac{1}{2 \times \sqrt{\frac{N}{A}}}$	$R = \frac{robsorved}{E(r)}$ (1)	Clark-Evans	Pommerenig, 2002
Tree Dimensions	$rij = \frac{\text{Smaller diameter}}{\text{Larger diameter}}$	$TD_i = \frac{1}{4}\sum_{j=1}^{4}(1-rij)$ (2) $HD_i = \frac{1}{4}\sum_{j=1}^{4}(1-rij)$ (3)	Diameter Differentiation Height Differentiation	Ruprecht et al., 2010
Tree Density	S_{ij}: distance from reference tree to neighbors	$D_i = \frac{1}{4}\sum_{j=1}^{4} Sij$ (4)	Nearest Neighbor Distance	Ruprecht et al., 2010

2.2.1. Nearest Neighbor Distance Index

This index index was used to address the shortcomings of nearest neighbor structural indices that do not consider forest stand density. Without calculating this index, differences between two forests with similar spatial arrangements but different densities may not be properly reflected. Therefore, the nearest neighbor distance index is used complementarily with other indices in quantifying forest structure (Ruprecht et al., 2010).

2.2.2. Uniform Angle Index

This index examines the regularity of the spatial position of the reference tree relative to its neighboring trees by comparing the angle between neighboring trees with a standard angle. When four neighboring trees are used, the uniform angle index can take one of the following values: 0, 0.25, 0.50, 0.75, or 1 (Ruprecht et al., 2010). Values less than 0.3 indicate a uniform pattern, values between 0.3 and 0.4 indicate a random pattern, and values greater than 0.4 indicate a clumped pattern (Pastorella & Paletto, 2013). Since the value of this index is only an average number, plotting the distribution of its values can provide more detailed information about the spatial position of the studied forest stands (Szmyt, 2014).

2.2.3. Mingling Index

This index describes the degree of mingling among tree species in the forest and is expressed as the fraction of the nth nearest neighbors that belong to a different species than the reference tree (Szmyt, 2014). This index ranges from 0 to 1. Values less than 0.3 indicate low mingling (species diversity), values between 0.3 and 0.5 indicate moderate mingling, and values greater than 0.5 indicate high mingling (Pastorella & Paletto, 2013). In other words, as the value of this index increases, species mingling in the studied stand also increases.

2.2.4. DBH and Height Differentiation Indices

These indices examine the homogeneity or heterogeneity of trees in terms of DBH and height. The values of these indices range from 0 (no difference and all trees are completely similar in dimensions) to 1 (high heterogeneity among neighboring trees) (Szmyt & Dobrowolska, 2016). If neighboring trees show little difference, the index tends toward 0, whereas high heterogeneity among neighboring trees causes the index to approach 1. For better interpretation, the results of this index are divided into three classes: low diameter or height differentiation (values less than 0.3), moderate differentiation (values between 0.3 and 0.5), and high differentiation (values greater than 0.5) (Pastorella & Paletto, 2013). For coppice bases, coppice group diameter and dominant coppice group height are used instead of DBH and tree height, respectively.

2.2.5. Diameter Dominance Index

This index, similar to the diameter and height differentiation indices, examines the dimensional diversity of trees. If the diameter of the reference tree is dominant over neighboring trees (TDi), the value of this index tends toward 1, and vice versa. For this index, values of 0, 0.33, 0.67, and 1 indicate low, moderate, apparent, and high differences, respectively. As with the diameter and height differentiation indices, coppice group diameter and dominant coppice group height are used instead of DBH and tree height for coppice bases.

2.2.6. Neighborhood Distance Index

This index specifies the competitive pressure (mainly crown competition) between the reference tree and neighboring trees. Values between 0 and 2 m indicate very intense competition, 2 to 4 m indicate intense competition, 4 to 6 m indicate moderate competition, and values greater than 6 m indicate low competition.

2.2.7. Combined Structural Diversity Index

This index describes three aspects of forest structure: spatial position, species diversity, and dimensional differences among trees. It evaluates structural diversity by assigning different weights to each of the three indices (Pastorella & Paletto, 2013; Szmyt & Dobrowolska, 2016). This index combines the uniform angle index, mingling index, and dimensional differentiation index, and its main purpose is to assess the level of biodiversity related to tree species in forest ecosystems. Considering the relative importance of the three structural aspects, each index is weighted accordingly (Pastorella & Paletto, 2013). Ti represents the dimensional differentiation index, Mi the mingling index, and Wi the uniform angle index (Equation 5).

$$SI = (T_i \times w_1) + (M_i \times w_2) + (W_i \times w_3) \qquad \text{Equation (5)}$$

Values less than 0.3 indicate low tree diversity, values between 0.3 and 0.4 indicate moderate tree diversity, and values greater than 0.4 indicate high tree diversity (Szmyt & Dobrowolska, 2016). In this research, each structural group consisted of one reference tree and its four neighboring trees. All trees were selected once as the reference tree, and their structural status relative to their neighbors was examined.

2.2.8. Clark-Evans Index

This index is used to determine the deviation of a forest stand from a Poisson distribution. In a forest with a random distribution, a Clark-Evans index value greater than 1 indicates a regular tree distribution, whereas values equal to or less than 1 indicate random and clumped distributions, respectively (Kunstler et al., 2004).

Calculations related to the structural characteristics of the studied stands were performed using Excel and SPSS software, while calculations related to structural indices were performed using the Crancod software package.

3. Results

3.1. Parikadan Sample Plot (Southern Slope)

More than 80% of of the bases in the Parikadan sample plot were formed by broadleaf species in two growth forms: high-forest and coppice (Table 3). However, information on accompanying species such as *Acer cinerascens* Boiss., *Lonicera nummularifolia* Jaub., and *Daphne mucronata* Royle. was also recorded in this sample plot. Two *Pistacia atlantica* Desf. individual trees were also present in this area.

Descriptive statistics of the examined variables (for both single-stem and coppice trees) are presented in Table 4. The elliptical formula was used to calculate crown area.

Table 3. Structural characteristics of the Parikadan sample plot

Variable	High forest		Coppice		Other Species			Total
	***Quercus brantii* Lindl.**	***Pistacia atlantica***	***Acer cinerascens***	***Quercus brantii***	***Amygdalus scoparia* Spach.**	***Lonicera nummulariifolia***	***Daphne* sp.**	
Density (per hectare)	36	2	3	95	20	6	1	163
Percentage (%)	22.1	1.2	1.8	58.2	12.3	3.7	0.6	100

Table 4. Descriptive statistics of quantitative variables of two growth forms in the Parikadan sample plot

Growth form	Characteristic	Minimum	Maximum	Mean	Standard Deviation
Coppice	Number of Shoots per Coppice Group	2	15	5.14	3.3
	Average Coppice Group Diameter (cm)	7.50	32.7	15.3	4.4
	Basal Area (cm²)	3.8	154	84.3	42.8
	Small Crown Diameter (m)	2.3	11.7	6.2	2.1
	Large Crown Diameter (m)	2.8	16.2	7.9	2.8
	Average Crown Diameter (m)	2.6	12.9	7.1	2.3
	Coppice Group Crown Area (m²)	5.0	123.7	42.1	25.9
	Height of Tallest Shoot (m)	3.4	12.5	7.0	2.0
High forest	DBH (cm)	6.2	49.0	17.4	12.3
	Basal Area (cm²)	13.8	1884	356	512
	Small Crown Diameter (m)	1.4	11.8	4.4	2.6
	Large Crown Diameter (m)	2.0	14.7	5.9	3.5
	Average Crown Diameter (m)	1.7	12.6	4.9	2.9
	Height (m)	3.1	16.6	6.7	3.0

The average nearest neighbor-based structural indices calculated for the Parikadan sample plot are presented in Table 5.

To provide more detailed information on the structural status of the species present in the stand, Table 6 presents the structural status of each species relative to neighboring trees.

Table 5. Average nearest neighbor-based structural indices in the Parikadan sample plot

Feature	Index	Mean Index	Description
-	Number of Structural Groups Before Edge Correction	163	-
-	Number of Structural Groups After Edge Correction	136	-
Density	Nearest Neighbor Distance Index (NND)	3.34	Average First Tree
Spatial Pattern Diversity	Uniform Angle Index (UAI)	0.55	Clumped
-	Clark-Evans Index (CEI)	0.61	-
Species Mingling Diversity	Mingling Index	0.23	Low Mingling
Dimensional Diversity	Diameter Differentiation Index (DDI)	0.33	Diameter at 0.5 m Height
-	Crown Cover Differentiation Index (CCDI)	0.56	-
-	Diameter Dominance Index (DDoI)	0.51	-
-	Crown Cover Dominance Index (CCDoI)	0.52	-
-	Neighborhood Distance Index (NDI)	5.66	Average 4 Trees
-	Combined Structural Diversity Index	0.39	Diameter at 0.5 m Height

Table 6. Average nearest neighbor-based structural indices by species in the Parikadan sample plot

	Number of Structural Groups		Structural Indexes								
Species	B E C	A E C	N N D	UA*	C E	Mingling	D D	C C D	D Do	C C Do	N D
Quercus	131	109	3.57	0.55	0.59	0.15	0.35	0.56	0.55	0.57	5.98
Acer	3	3	3.54	0.42	0.08	1.0	0.28	0.50	0.33	0.33	6.03
Amygdalus	20	16	2.28	0.63	0.15	0.22	0.27	0.46	0.41	0.42	3.52
Daphne	1	1	4.47	0.50	0.06	1.0	0.69	0.73	0.00	0.25	10.26
Pistacia	2	1	2.23	0.50	0.04	1.0	0.16	0.83	0.50	0.25	6.89
Lonicera	6	6	1.93	0.58	0.06	0.96	0.28	0.74	0.29	0.00	4.54

*The full title of the words is given in Table 5.

3.2. Sarabtaveh Sample Plot (Northern Slope)

More than 90% of the bases in the Sarabtaveh sample plot were formed by broadleaf species in two growth forms: single-stem and coppice (Table 7).

Descriptive statistics of the examined variables (for both single-stem and coppice trees) are presented in Table 8. The elliptical formula was used to calculate crown area.

The average nearest neighbor-based structural indices calculated for the Sarabtaveh sample plot are presented in Table 9.

To provide more detailed information on the structural status of the species present in the sample plot, Table 10 presents the structural status of each species relative to neighboring trees.

Table 7. Structural characteristics of the Sarabtaveh sample plot

Variable	High forest		Coppice	Other Species	Total
	Quercus brantii	*Pistacia atlantica*	*Quercus brantii*	*Crataegus azarolus* L.	
Density (per hectare)	13	1	83	6	103
Percentage (%)	12.6	0.97	80.5	5.9	100

Table 8. Descriptive statistics of quantitative variables of two forms growth in the Sarabtaveh sample plot

Growth form	Characteristic	Minimum	Maximum	Mean	Standard Deviation
Coppice	Number of Shoots per Coppice Group	1	13	5.14	2.76
	Average Coppice Group Diameter (cm)	3	41.9	14.4	7.1
	Basal Area (cm²)	7	176	84.9	45.5
	Small Crown Diameter (m)	2.4	14.7	5.6	2.1
	Large Crown Diameter (m)	2.5	15.7	6.7	2.4
	Average Crown Diameter (m)	2.5	15.2	6.2	2.2
	Coppice Group Crown Area (m²)	5.0	123.7	42.1	25.9
	Height of Tallest Shoot (m)	2.5	11.3	6.8	1.8
High forest	DBH (cm)	6.0	70.0	19.5	15.7
	Basal Area (cm²)	28.3	1045	491	250
	Small Crown Diameter (m)	1.3	10.3	3.5	2.3
	Large Crown Diameter (m)	1.4	12.5	4.4	2.7
	Average Crown Diameter (m)	1.3	11.4	3.9	2.4
	Height (m)	3.1	12.8	5.8	2.2

Table 9. Average nearest neighbor-based structural indices in the Sarabtaveh sample plot

Feature	Index	Mean Index	Description
-	Number of Structural Groups Before Edge Correction	103	-
-	Number of Structural Groups After Edge Correction	84	-
Density	Nearest Neighbor Distance Index (NNDI)	4.92	Average First Tree
Spatial Pattern Diversity	Uniform Angle Index (UAI)	0.52	Clumped
-	Clark-Evans Index (CEI)	1.13	-
Species Mingling Diversity	Mingling Index	0.14	Low Mingling
Dimensional Diversity	Diameter Differentiation Index (DDI)	0.32	Diameter at 0.5 m Height
-	Crown Cover Differentiation Index (CCDI)	0.57	-
-	Diameter Dominance Index (DDI)	0.49	-
-	Crown Cover Dominance Index (CCD)	0.48	-
-	Neighborhood Distance Index (NDI)	7.21	Average 4 Trees
-	Combined Structural Diversity Index (CSDI)	0.55	Diameter at 0.5 m Height

Table 10. Average nearest neighbor-based structural indices by species in the Sarabtaveh sample plot

	Number of Structural Groups		Structural Indexs									
Species	B E C	A E C	NND	UA	CE	Mingling	DD	CCD	DDo	CCDo	ND	CSD
Quercus	96	80	4.87	0.51	0.76	0.06	0.37	0.51	0.51	0.52	8.82	0.31
Crataegus	6	4	5.47	0.50	0.15	1.0	0.28	0.51	0.25	0.52	9.40	0.31

4. Discussion

Determining the structural characteristics of forest stands is essential for examining stand dynamics and planning silvicultural interventions such as thinning and rehabilitation operations. Based on the results obtained, it was found that the majority of trees in the studied habitats were in the coppice or branch-derived growth form. However, in the Parikadan region (southern slope), the percentage of coppice trees was higher than in the Sarabtaveh region, which may indicate greater degradation of this region compared to Sarabtaveh. Examination of density and canopy cover status in the studied regions (Table 1) also showed that the Sarabtaveh stand, due to degradation and natural disturbances, is not in a favorable condition. In a study, the density and canopy cover status of two stands in West Azerbaijan Province were examined, and it was concluded that degraded stands have lower density and canopy cover, which is consistent with the results of this research (Henareh et al., 2024). In terms of diameter structure, in both habitats, the frequency of trees with small diameters was dominant, and large trees had lower frequency, which may indicate an uneven-aged structure in both habitats.

The results of this research showed that the maximum DBH in the Sarabtaveh region was 70 cm, and the overall average DBH was estimated at 19.5 cm, which shows greater irregularity compared to the Parikadan region with a maximum DBH of 49 cm and an average DBH of 17.40 cm. Additionally, in terms of basal area, the Sarabtaveh habitat had better conditions than Parikadan. Researchers consider the increase in beech tree diameter as one of the important characteristics in improving the overall structure of forest stands (Milorad & Damjan, 2004). A study conducted in coppice oak forests in Ilam Province also indicated the presence of irregular uneven-aged stands in that region. They also introduced tree diameter and basal area as suitable characteristics for quantifying forest stand structure (Hosseinzadeh et al., 2004). The results indicate moderate diameter differentiation in the Chahar Zabar sample plot and low differentiation in the Barzeh sample plot. In terms of height differentiation, both plots exhibited low variability. These findings can be attributed to the presence of multiple degrading factors in the Zagros forests and the studied areas, which have prevented forest stands from having sufficient time and capacity to reach advanced developmental stages (Rahimi et al., 2023). As a result, all trees and coppice groups have been continuously subjected to destructive stresses, limiting significant diameter and height differentiation (Henareh et al., 2024).

Providing stand structural characteristics while considering climatic changes and the intensity of interventions in western forests can provide solutions for developing more appropriate and compatible management plans for stands in these regions. This research quantified the structure of tree communities in these regions. The average DBH for trees in both studied regions was below 25 cm, and the average height was between 5 and 7 meters. It seems that one of the most important reasons for the small diameter of trees, in addition to human-induced disturbances, is the effects of climate change and drought in past periods, which have somewhat reduced the growth capacity of trees.

The diameter differentiation index for Parikadan and Sarabtaveh was 0.33 and 0.32, respectively. That is, this index for both sample plots was on average below 0.36, indicating no significant statistical difference in DBH and the homogeneity of trees in terms of diameter. In a study examining the spatial structure of beech in a mixed forest, the average diameter differentiation index was 0.53, which is not consistent with the results of this study (Alijani et al., 2012). The reason for this may be due to regional differences and consequently differences in the studied stands. As a result, trees become more heterogeneous in terms of diameter and show more differentiation. In a study, the diameter differentiation index for the Chahar Zabar and Barzeh habitats in Kermanshah Province was calculated as 0.55 and 0.38, respectively, with the results obtained from the Barzeh habitat consistent with the results of this research (Rahimi et al., 2023).

The results of the uniform angle index in this research for both studied regions were greater than 0.4, indicating a clumped structure of oak trees in the region. The results obtained from this index are consistent with studies (Kunstler et al., 2004; Basiri et al., 2006; Mouro et al., 2007; Haidari et al., 2022) that have all introduced the pattern of different species of the oak genus as clumped. Given the seed production mechanism of oak species and their reliance on producing heavy seeds that tend to disperse locally around mother trees, leading to high seed density around mother trees, a clumped pattern for oak is not unexpected. The average value of this index in the studied sample plots indicates a clumped arrangement of trees relative to each other, which can be attributed to changes and degradation in the region's forests.

The mingling index for Parikadan and Sarabtaveh was 0.23 and 0.14, respectively. Since the studied forest stands have been under stress in the past and favorable habitat conditions do not exist in the region (Rahimi et al., 2023), the number of tree species is low, and the stands are mostly composed of one or two main species, the low mingling index is justifiable, especially since Persian oak is the main species in the studied areas. The low numerical value of this index indicates the existence of conditions for interspecific competition (Sefidi et al., 2020). However, this may be due to regional weakness resulting from past disturbances that have eliminated the possibility of survival and reproduction of other species under the current regional conditions. This result is consistent with research (Farhadi et al., 2019) in Zagros forests. In pure forest stands where the abundance of one species exceeds 70%, the mingling index is low. In this research, where the main species in the studied area is Persian oak, this is not unexpected. On the other hand, species mingling is directly influenced by the distribution pattern of trees, so oak, which has a clumped distribution, causes neighboring trees to mostly be oak (Pommerening, 2002). The mingling index clearly shows the differences in the structure of different species. This index provides appropriate information about intraspecific and interspecific competition among trees. Overall, the results of this index indicate low mingling of the studied species. In a study, it was stated that species mingling is influenced by the spatial position of trees, and species with a clumped pattern usually have low mingling (Pommerening, 2002).

The average nearest neighbor distance index for the Parikadan sample plot was 5.66 and for the Sarabtaveh sample plot was 7.21. The results obtained from this index in the Parikadan region are consistent with research in the Asalem forests of Gilan (Farhadi et al., 2017). This index indicates the density of forest stands or, in other words, the number of tree bases per unit area and can represent the competitive pressure among trees in stands (Pommerening, 1997). As the distance between trees increases and, consequently, the nearest neighbor distance index increases, the density of forest stands decreases (Kakavand et al., 2015). In a study, it was stated that the average of this index depends on the arrangement of trees and the density of the studied forest and easily allows calculating the average distance between trees in a structural group and comparing it with other areas (Ruprecht et al., 2010). Also, Farhadi et al. (2017) used the nearest neighbor distance index to show the reduction in tree density in Hyrcanian forests due to the degradation of local communities by comparing tree density before and after degradation (current conditions).

The Clark-Evans index for Parikadan and Sarabtaveh was 0.61 and 1.13, respectively. According to the results obtained, since the index value for the Sarabtaveh area is greater than the base value of 1, the tree distribution pattern in this region is regular, and for the Parikadan habitat, considering the obtained index value and the base value, the tree distribution pattern is clumped. Ecological distribution research results have shown that two main factors determine the distribution pattern of trees in a forest: providing suitable growth space and the reproductive strategy of each plant (Fujimori, 2001). In conditions where growth spaces (from biological deficiencies to various competitions) are limited for tree species, the tendency of tree bases (especially habitat-sensitive species) to clump or become uniform increases, and they move away from random distribution patterns (Fangliang et al., 1997). Trees that have heavy seeds or reproduce through root suckers and shoots also tend to clump (Schulze et al., 2005). However, the results of each study should not be compared with predetermined patterns. For example, although trees of a species may not have growth limitations in a habitat, due to limited genetic content, they may not be able to show the random distribution pattern expected of them. Mou et al. (1993) also pointed out that in species where the dominant regeneration form is asexual (e.g., root suckers and shoots), the established patterns are largely influenced by the initially created pattern. In this research, the spatial distribution pattern for the dominant species (Persian oak) in the two monitored areas was clumped, which is consistent with the results of other researchers

(Fangliang et al., 1997). In limited studies, other patterns have been mentioned for Persian oak in Zagros forests, including random patterns in Servak forests of Yasouj (Erfani Fard et al., 2008) and uniform patterns in Bolouran Forest Park in Kuhdasht County (Nazarpour Fard & Pourbabaei, 2019). The reason for this difference may be the level of interventions in the areas, differences in the scale studied, and the indices used.

The average neighborhood distance index in the studied areas clearly indicates the sparse nature of the trees and the increase in their distance from each other. As the distance between trees increases and, consequently, the neighborhood distance index increases and stand density decreases, competition among trees also decreases.

By using nearest neighbor indices, in addition to describing the current status of forests and the species present in them, changes over time and space can be examined, and differences between the biodiversity and structure of managed and unmanaged or non-protected forests can be assessed.

5. Conclusion

Unfortunately, due to uncontrolled human interventions in these forests, untouched stands are very rare in these areas, and the best method of examination in these areas is to compare the structure of stands relative to each other. Since the characteristics of the studied regions in this research are very similar in terms of general features, their sequence can be traced by comparing them. Overall, the comparison and examination of the two regions indicate that in terms of all structural characteristics, including DBH, tree height, basal area, density, and regeneration (based on visual observations), the Parikadan and Sarabtaveh regions are not in a favorable condition. The differences in structural characteristics between the two regions indicate the relative distance and proximity of each to the final desirable structure of these forests.

Understanding the structure and quantitative and qualitative characteristics of natural regions makes it possible to adopt appropriate methods for maintaining the sustainability of these ecosystems by considering the potential of each plot and applying close-to-nature silviculture principles. It seems that, considering the evident human interventions in these forests and their impact on forest structure, appropriate decisions—such as preparing long-term plans aimed at improving forest structure and performing suitable silvicultural operations—can gradually convert the structure of existing forests from coppice to high forest and improve the overall condition of these stands. Additionally, to combat the degradation trend, monitoring biological and non-biological indices, prioritizing conservation programs (including preventing livestock entry into the area), controlling and storing atmospheric precipitation, increasing soil moisture, and rehabilitating damaged areas are all essential and should be pursued simultaneously.

It is recommended that the interaction between physiographic factors, soil, and environmental factors on stand structure be examined in different habitats. This would provide comprehensive information for the optimal management of these valuable stands for forest managers and silviculturists.

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تحلیل ساختار توده‌های جنگلی قرق نشده در شهرستان بویراحمد

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چکیده

امروزه توصیف کمی ساختار جنگل به عنوان یکی از مناسب‌ترین ابزار در مدیریت نوین جنگل درنظر گرفته می‌شود. بنابراین برای مدیریت صحیح اکوسیستم‌های جنگلی، داشتن اطلاعات کافی در رابطه با ساختار گونه‌های درختی ضروری است. این پژوهش در چارچوب طرح جامع سنجش و پایش جنگل‌های زاگرس که با روش پایش مکان‌محور (Place-base monitoring) طراحی شده است، به ارزیابی ساختار دو توده سرآب‌تاوه (Sarabtaveh) در دامنه شمالی و پریکدان (Parikadan) در دامنه جنوبی در جنگل‌های شهرستان بویراحمد از استان کهگیلویه و بویراحمد می‌پردازد. در هریک از رویشگاه‌ها، قطعه‌نمونه یک‌هکتاری مربعی‌شکل به‌صورت تصادفی پیاده و متغیرهای کمی پایه‌های درختی اندازه‌گیری شد. براساس نتایج، در هر دو رویشگاه فرم غالب درختان توده، جست‌گروه یا شاخه‌زاد بودند. الگوی پراکنش مکانی برای گونه غالب در هر دو منطقه یعنی بلوط ایرانی، کپه‌ای به‌دست آمد. مقدار شاخص آمیختگی در توده پریکدان (۰/۲۳) و در توده سرآب‌تاوه (۰/۱۴) محاسبه شد که بیانگر تنوع گونه‌ای بیشتر در توده پریکدان نسبت به رویشگاه سرآب‌تاوه می‌باشد. البته شاخص آمیختگی هر دو رویشگاه کم بوده و با توجه به اینکه گونه بلوط تشکیل دهنده اصلی مناطق مورد بررسی می‌باشد، این مسئله قابل توجیه است. مقدار شاخص کلارک-ایوانز برای رویشگاه‌های پریکدان و سرآب‌تاوه به‌ترتیب ۰/۶۱، ۱/۱۳ به‌دست آمد. شاخص تمایز قطری برای رویشگاه‌های پریکدان و سرآب‌تاوه نیز به‌ترتیب ۰/۳۳، ۰/۳۲ بدست آمد. که نشان دهنده‌ی عدم اختلاف بین درختان از نظر متوسط قطر برابر سینه و همچنین همگن بودن درختان از نظر قطری می‌باشد. اندازه‌گیری و محاسبه شاخص زاویه یکنواخت، شاخص‌های چیرگی قطر، سطح تاج پوشش، شاخص فاصله همسایگی، شاخص تنوع ساختاری و غیره از دیگر نتایج تحقیق پیش‌رو می باشد. نتایج حاصل از این شاخص‌ها مبنایی برای مقایسه با سایر جنگل‌های مشابه و تعیین میزان انحرافات ناشی از فرآیندهای طبیعی و دخالت‌های انسانی خواهد بود. این مقایسه به تدوین یک الگوی مدیریت و شیوه جنگل‌شناسی مناسب در جنگل‌های منطقه کمک می‌کند.

واژه‌های کلیدی: آمیختگی، بلوط، پریکدان، جنگلداری، زاویه یکنواخت.

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