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Impact of long and short-term conservation periods on structure of English yew (*Taxus baccata L.*) in Arasbaran forests, Iran

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Abstract: Yew (*Taxus baccata* L.) is one of the most important and threatened tree species in the Arasbaran region of northwestern Iran. To understand the natural stand structure of yew forests to inform forest management, we assessed the structural characteristics and composition of yew communities using the nearest neighbour and full callipering method at three sites with different conservation histories. Within a one-hectare sampling area, tree species identity, diameter, height, and crown diameter were measured. In each of these sampling areas, 56 sample points were surveyed in a 25 m × 25 m grid for tree species identity, diameter, height, and distance from reference to neighbour trees. To quantify the structural characteristics in areas of different conservation status, some indices were calculated including mingling, distance between reference tree and its nearest neighbouring trees, diameter and height differentiation, uniform angle, and Clark-Evans index. Results revealed that four species – hornbeam (68%), maple (8%), yew (7%), and oak (5.2%) – composed 88% of the tree species. The majority of trees had a short distance (2–3 m) between neighbours. The mean diameter differentiation index for long-term and short-term conservation areas was 0.59 and 0.06, respectively. The uniform angle index showed that there was no class value = "1" at all three sites. In the long-term enclosed area, Clark-Evans index was 1.18. In short-term enclosed areas, it was less than 1 (0.82). At all sites, yew trees were in the least vital class. We conclude that enclosing affects the yew stand structure, specifically in long-term periods of enclosure.

Keywords: conservation-based management; diameter differentiation; forest structure; nearest neighbour

Forest management plans aim to conserve the natural stand structure through a range of management and conservation activities. Forest structure is necessary in the formation and maintenance of many forest ecosystem functions. Investigating the pattern of spatial structure can inform about ecological and forestry issues (Karimi et al. 2012). High species diversity and ecological stability of a stand are often related to increased heterogeneity in the horizontal and vertical stand structure (Pommerening 2002). Silvicultural operations can help to improve the stand structure and sustainability, and maintain species diversity in a stand (Pommerening 2002).

The structure of forest stands can be defined using three metrics: the shape, size, and spatial distribution of trees (Sefidi et al. 2015). There are different measurement and computational methods for quantifying the structural indices of the stand. The study of stand structure using the nearest neighbour indicator is one of the most suitable methods (Nouri et al. 2015; Pommerening 2002). The nearest neighbour indicators are used to quantify the distance between a reference tree of a target species in relation to neighbouring trees. These indicators are accurate, low cost, easy to measure, and are sufficient to describe forest stands (Nouri et al. 2015; Sefidi et al. 2015).

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Arasbaran broadleaved forests, found in northwestern Iran, have an outstanding conservation value because of their high levels of biodiversity (Sagheb-Talebi et al. 2014). More than half of these forests were designated as a UNESCO biosphere reserve in 1976. Yew, an endangered, slow-growing, long-lived species (e.g. trees up to 1,500 years of age have been reported) is one of the key tree species found in Arasbaran forests. As a shade tolerant species, yews occur in the understorey of humid forest (Yazdani et al. 2005; Dhar et al. 2007). While they are able to tolerate low light conditions, higher light conditions can facilitate their better growth (Dobrowolska et al. 2017).

To better manage yew stands, an understanding of the natural stand structure of this species in forests is critical. In the Hyrcanian region of Iran, Esmailzadeh and Hosseini (2007) described yew communities that are co-dominated by European (*Carpinus betulus)* and Oriental hornbeam (*Carpinus orientalis*). In Arasbaran forests yew can also occur in stands with oak (*Quercus*) and maple (*Acer*) species (Ghanbari Sharafeh et al. 2010). In the past, yew had been removed from these forests. There has been regeneration of yew since then, estimated at 520 saplings per hectare, and these seedlings show high vitality (Ghanbari Sharafeh et al. 2010).

The structure of yew forests have been investigated throughout the world, using different indices (Dhar et al. 2006; Ruprecht et al. 2010). The variation of habitat conditions has led to differences in various structural indices such as diameter and height differentiation, mingling, and vitality. The spatial pattern of tree species has been studied by the uniform angle index, the mingling index, and the differentiation index in beech forests of Denmark. In the Hyrcanian forests Golbaian et al. (2016) found that the diameter distribution curve of yew trees was composed of even-aged stand with a two-layer structure. In these stands, yew trees reached a maximum height of 30 m, a maximum diameter of 2 m, and accounted for 100 $m^3 \cdot ha^{-1}$ stand volume.

Interest in yew conservation has been prevalent throughout Europe in recent years (Devaney et al. 2014; Casals et al. 2015; Dobrowolska et al. 2017). Conservation-based management practices like selective stand thinning to reduce the basal area of other species is one approach that may be effective at increasing yew prevalence throughout forest systems (Dobrowolska et al. 2017). However, in order to develop prescriptive management methodologies, a good understanding of the original forest stand structure is necessary. Therefore, the main aim of this study was to understand the structural characteristics and composition of yew forest communities in Arasbaran forests by assessing the distance by the neighbour method and tree diameters of trees across three sites. This research highlights the implications of the short- and long-term use of forest enclosures for the stand structure of these forests.

MATERIAL AND METHODS

Study area

Three sites in the Ilghanachay and Horand watersheds of Arasbaran, Iran, where yew is naturally distributed were selected for this study. Across all three sites, yew distribution ranges from approximately 800 to 1,600 m above sea level (Ebady, Omidvar 2011). The average annual rainfall is between 300–500 mm and average temperature varies from 5°C to 14°C at different altitudes (Sagheb-Talebi et al. 2004).

The three sites differed in conservation background and short- and long-term enclosure periods (Table 1; Ebady, Omidvar 2011; Ghanbari et al. 2010). Although all three areas were protected, they differed in access and protection status: Kalaleh (SKA) site and Vaygan site (SVA) were protected 42 years ago, and experienced a low human impact due to their distance from the village. The third site, Kuran (SKU), was protected eight years ago and is easily accessible by rural communities because of its proximity to the village.

Sampling method and data analysis

After determining the distribution area of this species at all three sites, three one-hectare sample plots from each site, for a total of nine hectares, were selected and inventoried (Akhavan et al. 2012). The inventory was done in each sample plot using two methods: full callipering and nearest neighbour (Wadt et al. 2005). For the full callipering method, we measured tree characteristics (at 1.3 m height, diameter at breast height (DBH) ≥ 7.5 cm) such as type of species, tree height with DBH ≥ 7.5 cm, distance and azimuth of each tree from the reference point, DBH, and average crown diameter. Distance and azimuth of each tree from the previous tree (as a refer-

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Table 1. Geographic position and characteristics of studied sites in Arasbaran forests, Iran (site names are defined as: SKA – Kalaleh, SKU – Kuran, SVA – Vaygan

Site	Latitude/longitude	Conservation history and distance from village	Dominant tree species	Forest origin
SKA	38°56'14''N, 46°45'30''E	42 years (< 1 km)	hornbeam, oak, yew	coppice with standards
SKU	38°56'41''N, 47°26'19''E	8 years (< 1 km)	oak, hornbeam, yew	coppice
SVA	38°55'22''N, 46°44'57''E	42 years (> 1 km)	hornbeam, yew	coppice with standards

ence point for the next tree) were recorded. Distances and azimuths were later converted to the Cartesian coordinates (X, Y). This coordinate was added to the coordinate of the first tree (as a reference tree). All of the trees had a UTM coordinate system (Akhavan et al. 2012; Herrero-Jáuregui et al. 2012).

Using the nearest neighbour method, 56 sample points were surveyed in a 25 × 25 m grid inside the one-hectare sample plots. The nearest yew tree to the sample point was selected as a reference tree and the three closest trees to the reference tree as neighbour trees were measured. Also, measurement of distance and azimuth was done between reference and neighbour trees. In the case of the reference trees, we measured DBH, tree height with DBH ≥ 7.5 cm, distance and azimuth from the plot centre, the tree layer at the stand, vitality status, and average crown diameter. In addition to these items, distance and azimuth of neighbour trees from each other were recorded (Devaney et al. 2014; Dhar et al. 2006). The Clark-Evans index (*CE*) has different values. The value of *CE* = 1 indicates random distribution of trees, *CE* > 1 – regular and *CE* < 1 – clustering of individuals in the population (Szmyt, Korzeniewicz 2014). Unlike the *CE* index, uniform angle index is a single tree variable. Assuming complete regularity of the positions of the *n* nearest neighbours around a reference tree *i*, the expected standard angle α_0 between two neighbours would be equal to 360°/*n*. For example α_0 = 90° in a constellation involving four neighbours like our study (Pommerening 2002). Vitality of yew trees was classified by four classes: class 1 includes trees with full crown and clear and healthy leaves, class 2 are normal trees without any diseases, class 3 are trees with symptoms of limited diseases and feeble crown, and class 4 includes trees with symptoms of diseases, sparse and weak crown, and without enough seeding (Sefidi et al. 2015). Table 2 shows the indices of the stand structure used to quantify the structural characteristics of forest.

Table 2. The indices of the stand structure to quantify the structural characteristics of forest

Attributes of stand structure	Equation	Interpretation	Reference
Mingling	$M_i = \frac{1}{n}\sum_{i=1}^{n} v_{ij}$	$v_{ij} = \begin{bmatrix} 0 \rightarrow species_j = species_i \\ 1 \rightarrow species_j \neq species_i \end{bmatrix}$ *n* – number of sampled trees	(Pastorella, Paletto 2013)
Distance to neighbours	$D_i = \frac{1}{n}\sum_{i=1}^{n} s_{ij}$	S_{ij} – distance of i_{th} yew from j_{th} neighbour, *n* – number of sampled trees (*n* = 3)	(Ruprecht et al. 2010)
DBH and height differentiation	$T_i = \frac{1}{n}\sum_{i=1}^{n}(1 - r_{ij})$	$r_{ij} = \frac{\text{smaller DBH}}{\text{higher DBH}}$ $r_{ij} = \frac{\text{biggest tree height}}{\text{smallest tree height}}$ *n* – number of sampled trees	(Ruprecht et al. 2010; Szmyt, Korzeniewicz 2014)
Uniform angle index (UAI)	$W_i = \frac{1}{n}\sum_{i=1}^{n} v_{ij}$	$v_{ij} = \begin{bmatrix} 0 \rightarrow \alpha_j \geq \alpha_0 \\ 1 \rightarrow \alpha_j < \alpha_0 \end{bmatrix}$ *n* – number of sampled trees	(Corral-Rivas et al. 2010; Szmyt, Korzeniewicz 2014)
Clark-Evans index	$CE = \frac{r_A}{r_E}$	r_A – mean of the distance from the trees to their nearest neighbours, r_E – mean of the nearest neighbour distance in a stand with completely random tree distribution	(Pommerening 2002)

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Table 3. Characteristics of three study areas at different forest sites

Site	Species	Stems (ha)	Height (m)	DBH (cm)	Basal area ($m^2 \cdot ha^{-1}$)
SKA	yew trees	47	4.83	9.7	0.72
	other tree species	522	9.56	18.6	34.53
SKU	yew trees	6	4.04	9.5	0.078
	other tree species	12	4.3	10	0.189
SVA	yew trees	15	5.1	11.16	0.316
	other tree species	303	9.68	23.5	28.86

RESULTS

General non-spatial descriptions

The average height of yew trees with DBH ≥ 7.5 cm at the long-term sites (SKA and SVA) was about 5 m. These trees were located in the lower layer. At the short-term site (SKU), however, yew trees (4.04 m) had approximately the same height as other trees (4.3 m). The mean of DBH in SVA (11.16 cm) was relatively larger than at the other two sites. The percentage of yew trees varied between different conservation conditions. At the long-term conservation period sites, the percentage of yew trees was about 7% of all stand trees. At the short-term site, SKU, yew trees accounted for a high percentage (33%) of all stand trees. The quantitative characteristics of all three sites are presented in Table 3.

Species composition

Results showed that these species were at all three sites: hornbeam (*Carpinus betulus*), oak (*Quercus macranthera*), white oak (*Q. petraea*), maple (*Acer campestre*), yew (*Taxus baccata*), plum (*Prunus* sp.), Caucasian hackberry (*Celtis caucasica*), cornelian cherry (*Cornus mas*), wild apple (*Malus sieversii*), dogwood (*Cornus sanguinea*), walnut (*Juglans regia*), pear (*Pyrus* sp.), wild cherry (*Cerasus avium*), European ash (*Fraxinus excelsior*). Four species – hornbeam (68%), maple (8%), yew (7%), and oak (5.2%) – composed 88% of the tree species in the stand.

Stand structure

Fig. 1 shows the distribution of diameter classes at the three sites studied. A wide range of diameter classes was observed at the long-term sites as compared to the short-term site. At SVA, the distribution of diameter classes was almost a normal distribution. At all three sites, the yew was in the lowest diameter classes (7–12 cm). But yew trees at SVA had relatively high diameter dimensions. At SKU, the number of trees above 7.5 cm was much lower than at the remaining sites and the existing trees were distributed only in two diameter classes (Fig. 1).

The study of the distribution of height classes at all three sites showed that there was a significant difference between SKU and the other two sites. SKU had only two height classes. A wide range of height classes was observed at SKA (Fig. 2).

Spatial species mingling

Results showed that the mingling index had different values at the three sites (Fig. 3). The frequency of mingling value class 1 was 100% for SVA. The mingling value class 1 for SKA had an 85% frequency. But at SKU the mingling value class 0.33 had a high frequency (50%).

The characteristics of tree size differentiation

The mean diameter differentiation index (TD_i) was estimated at 0.59 and 0.06 in long-term and short-term conservation periods, respectively. Among all the sites, SKA had all of the TD_i classes (Fig. 4). Similarly to TD_i, the Height differentiation index (HD_i) varied at all three sites. The result of HD_i for SKU was observed only in the lower classes and was not found in the middle and high tree height differentiation classes (Fig. 5). At SKU, yew was of the same height as the other tree species such as oak and hornbeam. But, at the other two sites, yew was in the lower layer and of the lower height than other trees.

Tree spatial distribution

The uniform angle index showed that there was no class value 1 at the studied sites. At SKA, SKU, and SVA, class value 0 had a higher frequency than the other classes, and it was 45%, 50%, and 56%, respectively (Fig. 6). Based on the Clark-Evans index, the spatial distribution pattern of yew species was investigated at three sites (Fig. 7). At long-term sites, this index was 1.18. It was less than 1 (0.82) in the short-term period. Distance to neighbour (D_i)

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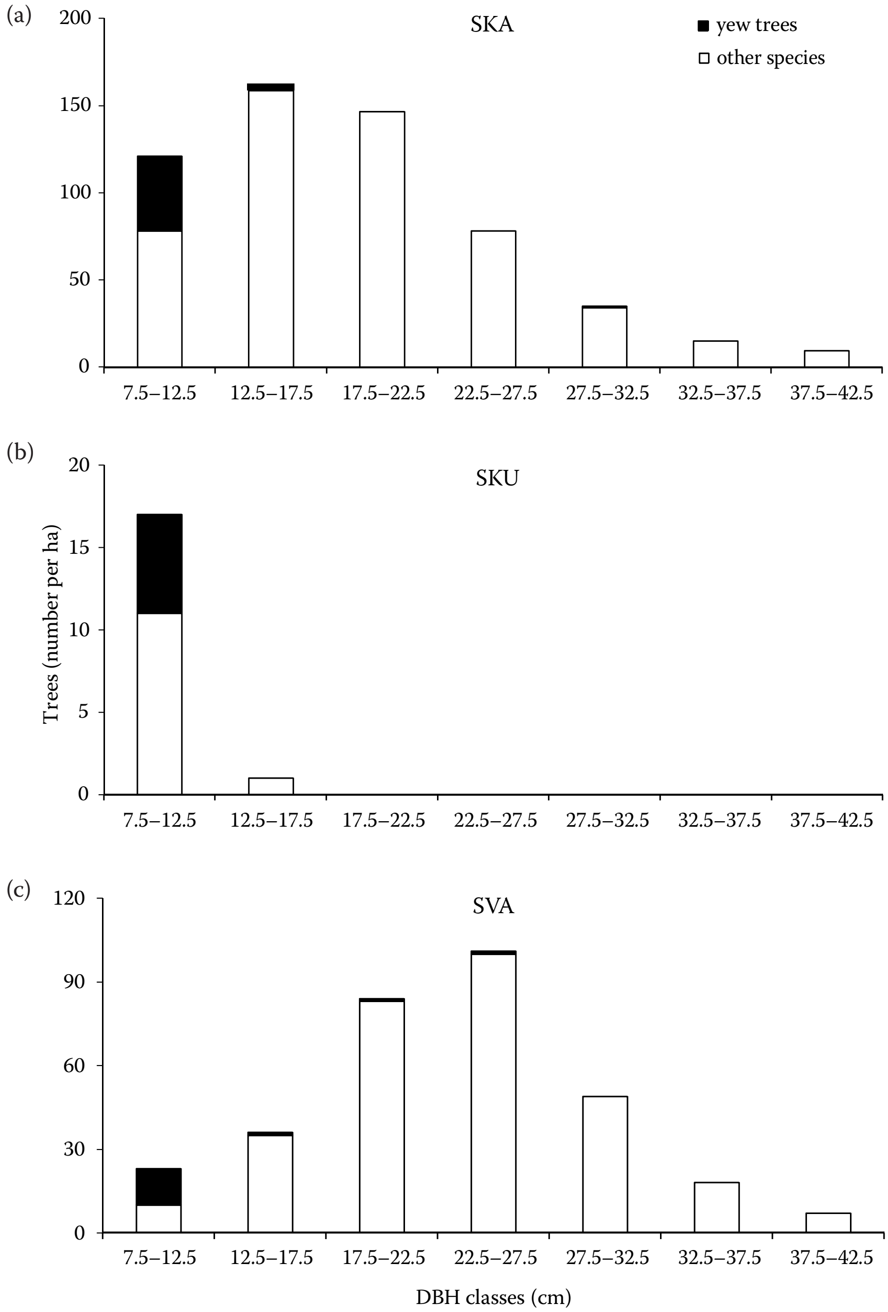

Fig. 1. Diameter class distribution for all tree species in three different management scenarios: SKA – Kalaleh site (a), SKU – Kuran site (b), SVA – Vaygan site (c)

index described the distance between the reference trees and neighbour trees. We found different values at the three sites for D_i index (Fig. 8). The highest percentage of trees at SKU (50%) and SKA (49%) had an average distance of 2–3 m. But at SVA, most of the trees (39%) had an average distance of 3–4 m. At SKU, the reference trees had a long distance to neighbour trees. Due to the low density of trees at SKU, 25% of the trees had a mean distance of more than 5 m. The majority of reference trees at the studied sites had a short distance (2–3 m) between the trees (Fig. 8). Due to the high density of trees at the sites with a long-term conservation period (SKA and SVA), a low percentage of trees had a mean distance of more than 5 m.

Vitality index is an important component in assessing the health status of the stand. This index showed that the majority of yew trees at SKA were in class 1 very vital (61%) and class 2 vital (37%) (Fig. 9). At SKU, the majority of trees (52%) were in class 1. But

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SVA had lower vitality than the other two sites. About 65% of the trees belonged to vitality class 2. None of the yew trees was in class 4 in the least vital class at three sites.

DISCUSSION

Yew as a rare conifer species in Arasbaran needs more consideration and new conservational strategies. Investigating the quantitative structure indices showed that sites with long-term conservation periods had higher values than short-term conservation areas. The differences in the quantitative values of these indicators can be related to the conservation history of these sites. Enclosing helps to reduce some anthropogenic disturbances like fuel gathering or tree removal and it helps to promote structural heterogeneity in forest stands. As results structural indices will be affected.

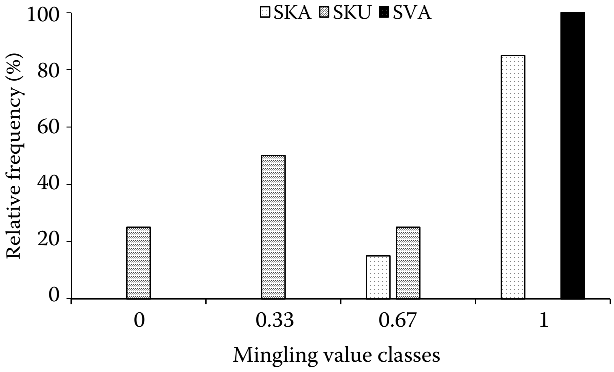

Fig. 3. The mingling value (DM_i) for three different management scenarios (SKA – Kalaleh site, SKU – Kuran site, SVA – Vaygan site)

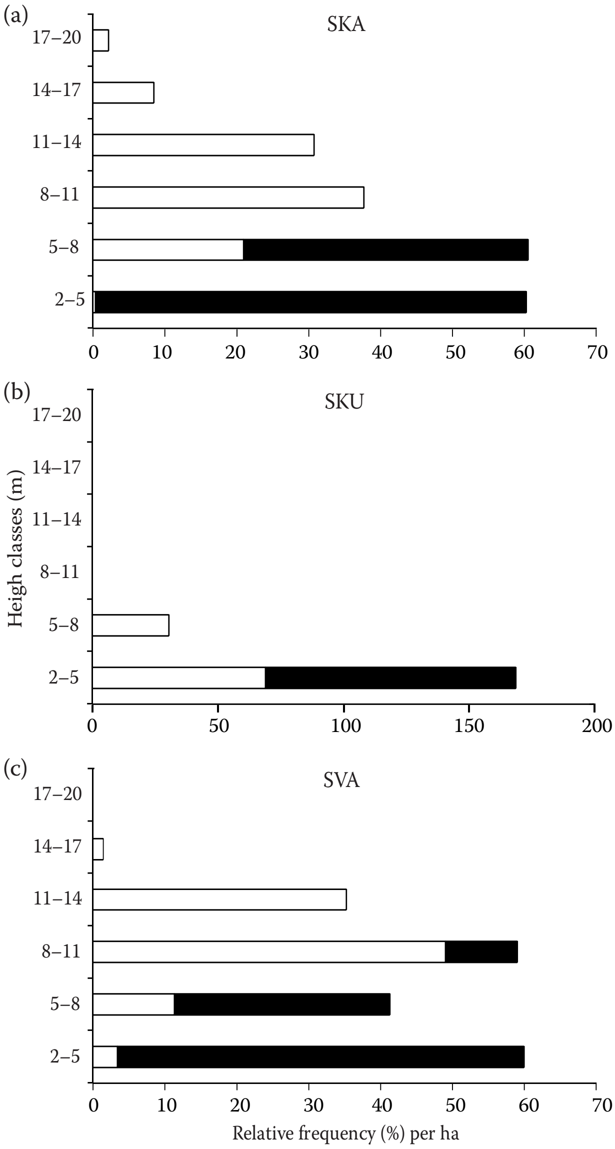

Fig. 2. Tree height class distribution for all tree species in three different management scenarios: SKA – Kalaleh site (a), SKU – Kuran site (b), SVA – Vaygan site (c)

Other studies have emphasized the importance of conservation in the improvement of the quantitative indices of the stand (Ghanbari Sharafeh et al. 2010; Devaney et al. 2014; Casals et al. 2015; Dobrowolska et al. 2017; Jafari Afrapoli et al. 2018). In northwestern Iran, the proximity of the village affects access of local people to tree stands at the sites we studied. Human-based disturbances always change the structure and composition of forest stands (Mishra et al. 2004). Conservation activities can help to revive the disturbed stands and ecosystem by reducing the severity of human-based disturbances. Two sites located in the long-term conservation periods had different access conditions. SKA and SVA had an easy and difficult access from the village, respectively. The mean DBH and height of SKA were smaller than at SVA. It seems that better conservation and more difficult access from the villages will create a better condition of stands in SVA. The diameter class distribution showed that yew trees were often in the class 12.5 cm. Jafari Afrapoli et al. (2018) found similar results which are partially justified due to the slow-growing nature of yew trees, although the average diameter is also influenced by site conditions. In other studies it was shown that a high number of trees had more than 12.5 cm in diameter (Dhar et al. 2006, 2007; Piovesan et al. 2009).

The average tree height showed that the yew trees ($H \approx 5$ m) were in the lower stand layer and had

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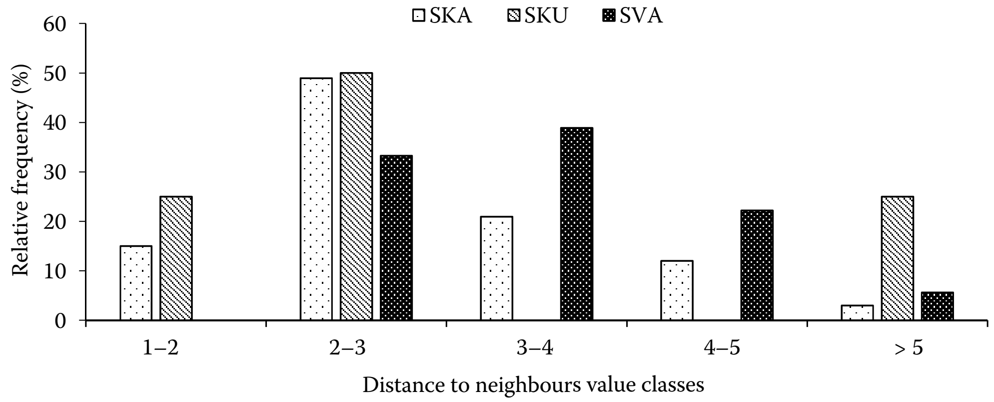

Fig. 4. Distance to neighbour (D_i) index for three different management scenarios (SKA – Kalaleh site, SKU – Kuran site, SVA – Vaygan site)

smaller height than the other trees of the stand ($H \approx 9.6$ m) at the long-term sites. At the short-term site, however, the yew had the same height as other trees and was in the upper forest layer. Yew trees were present because of the young age of other trees at SKU, which is a result of short-term conservation: the other species have not had enough opportunities for encroachment.

The mingling index value showed that the long-term sites had the highest value. A high percentage of reference trees were mixed with other species. But at the short-term site, SKU, the reference trees were often surrounded by yew species and there was an intraspecific competition. At SKU, about 50% of the yew trees were surrounded by two yew trees and one other tree. The weakening of maternal trees (Pilehvar et al. 2015), as well as the high mortality of yew trees at the lower age (Jafari Afrapoli et al. 2018) have reduced the competitive ability of this species compared to other species, to such an extent that other species are dominant at the yew sites. If the appropriate conservation guidelines are not performed well, it will endanger yew in these conditions. At the long-term sites, there was an interspecific competition between yew species and other species. This will lead to a reduction of yew tree vitality. Ruprecht et al. (2010) and Aguirre et al. (2003) also noted that mingling value and intraspecific and interspecific competition of sites depends on the site condition. The mingling index value indicated that the yew is mixed with other species. In addition, Pommerening (2002) stated that the high stand mixture between the reference trees and other species was observed in a randomized distribution pattern that is consistent with the results of our study. The D_i index showed that there was a shorter distance between the reference trees and other species at all

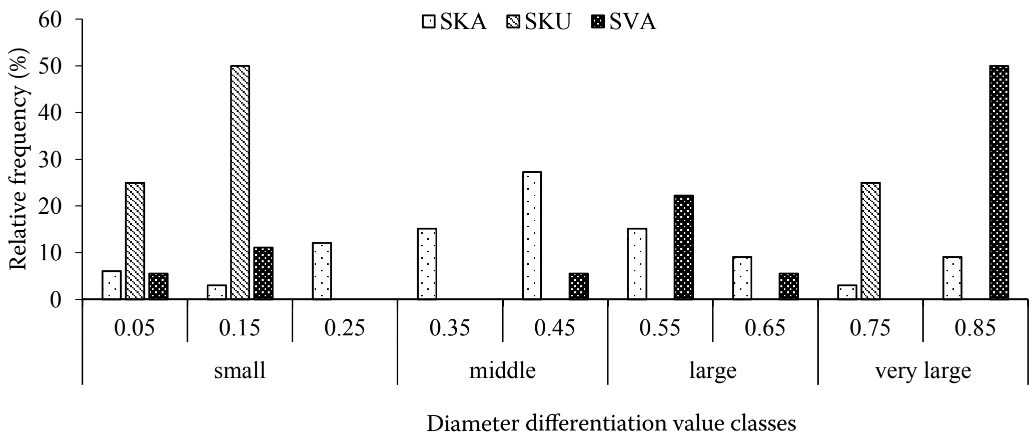

Fig. 5. Diameter differentiation (TD_i) index for three different management scenarios (SKA – Kalaleh site, SKU – Kuran site, SVA – Vaygan site)

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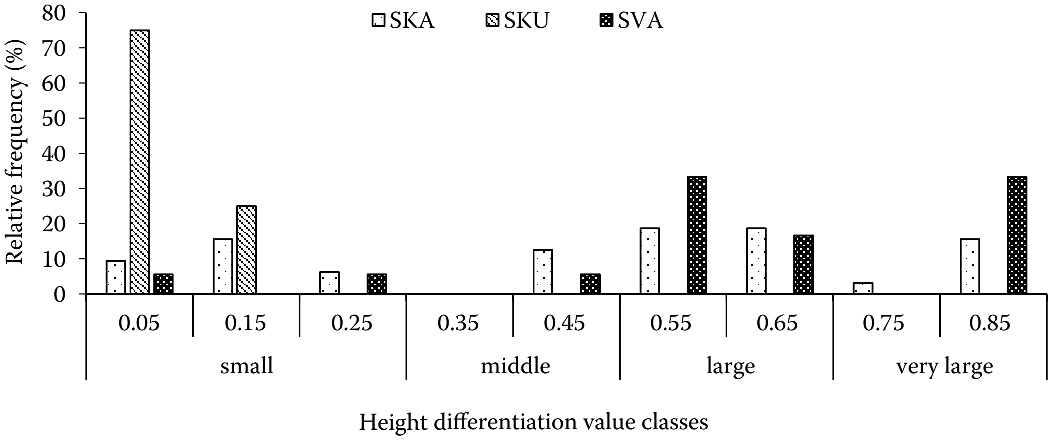

Fig. 6. Height differentiation (HD_i) index for yew trees in three different management scenarios (SKA – Kalaleh site, SKU – Kuran site, SVA – Vaygan site)

three sites. Most of the trees had a mean distance of 2 to 3 m at all three sites. A smaller D_i index can increase the interspecific and intraspecific competition, as was mentioned in other studies (Saniga 2000; Piovesan et al. 2009; Ruprecht et al. 2010; Devaney et al. 2014).

The average diameter differentiation index (TD_i) was estimated about 0.43, 0.06, and 0.75 for SKA, SKU, and SVA, respectively. TD_i value indicates relative homogeneity at SKA and SKU and relatively high heterogeneity at SVA. The height differentiation index was different at all the sites. SKA had a proportional distribution in different classes and approximately moderate heterogeneity. SKU had high homogeneity. HD_i value at SVA showed that high heterogeneity and high percentage of yew trees were in large and very large classes. The status of TD_i and HD_i showed that the conservation history did not have a significant effect on these indices.

The uniform angle index described the distribution pattern of trees. Regarding the value of this indicator, yew trees had a random and regular distribution in the study area. The spatial pattern of trees using the Clark-Evans index also showed that there was a random distribution at SKA and SKU and a regular distribution at SVA. As other researchers have stated, the random distribution can be observed in natural forests (Alijani et al. 2013; Farhadi et al. 2017), our study has been done in natural forests, too. In addition, the distribution of species is influenced by competition, stand disturbances, and the presence of invasive species in natural forests. Regular distribution of trees in the stands is a normal state of tree dispersal unless there is an artificial interference effect on the stand (Karimi et al. 2012).

The distribution pattern of a species can be influenced by site conditions, species botanical characteristics, species diversity, and human inter-

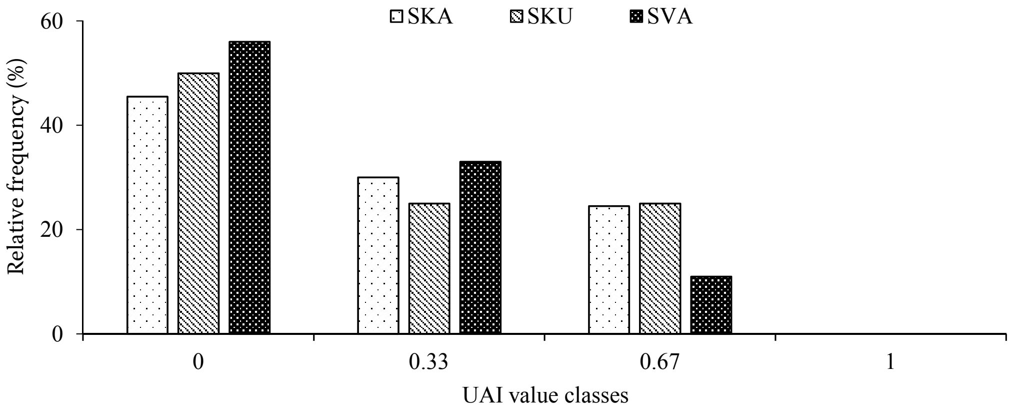

Fig. 7. Universe angle index (W_i) for three different management scenarios (SKA – Kalaleh site, SKU – Kuran site, SVA – Vaygan site)

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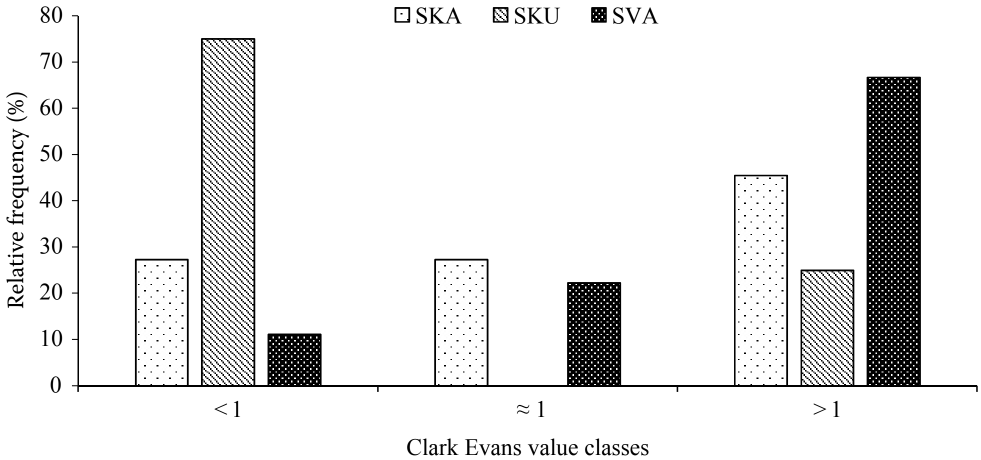

Fig. 8. Clark-Evans index for reference trees in three different management scenarios (SKA – Kalaleh site, SKU – Kuran site, SVA – Vaygan site)

ferences (Wei-Dong et al. 2001). Other scholars have mentioned the random distribution of trees in the forest. The regular pattern of stand trees can be due to an intense competition in the stand for limited resources. Karimi et al. (2012) mentioned some reasons for random patterns, such as tree mortality because of high density, site homogeneity, and transient patterns from clustering to regular. The random pattern of yew trees can be related to the site homogeneity. Luo et al. (2009) stated that species with a random distribution pattern have a low frequency in the study area, in line with our results (Luo et al. 2009). Results showed that more than 50% of the yew trees were very vital (class 1) and vital (class 2) at all three sites. Other researchers also stated that yew trees had high vitality. Dhar et al. (2006), in a vitality assessment of yew trees in Stiwollgraben, Austria, showed that more than 79% of the trees were in vitality class 1 and 2 (Dhar et al. 2006). In another study, the vitality of yew trees has been evaluated very vital (Katsavou, Ganatsas 2012). Vacik et al. (2015) however concluded that more than 50% of the yew trees were in less and very least vital classes (Vacik et al. 2015). The high vitality of yew stands indicates that other trees of the stand have provided optimal conditions for the yew tree growth (Katsavou, Ganatsas 2012).

In order to optimize the management of forest resources, it is essential to get the correct information about the structure of forest stands. It is important to obtain enough information about the forest stand structure and changes in various indicators of stand to offer new approaches to forest management. The results of this research can show the conservation effects on yew stands in long-term and short-term conservation periods. Reducing tree density and basal area of other species will lend strength to yew trees at the studied sites. However, because yew trees need moderate

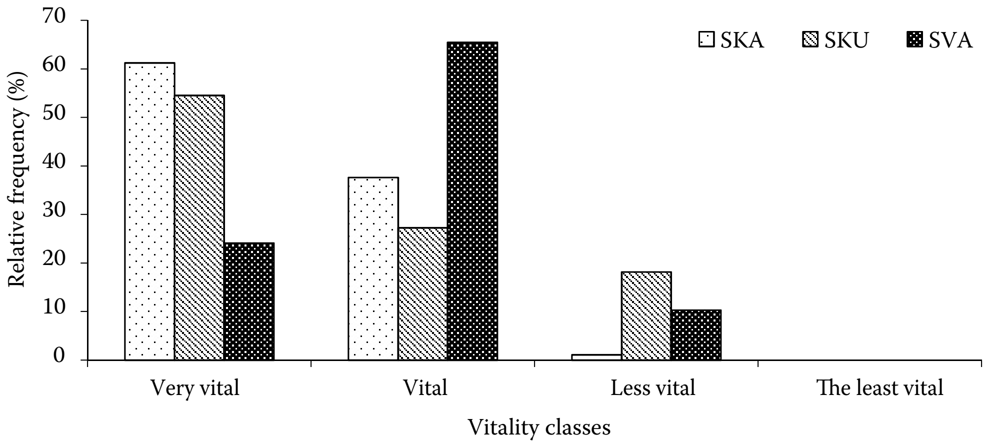

Fig. 9. Vitality classes of reference trees in three different management scenarios (SKA – Kalaleh site, SKU – Kuran site, SVA – Vaygan site)

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light conditions, excessive decreases in the tree density can be detrimental (Dhar et al. 2007).

CONCLUSIONS

The analysis based on structural incises revealed the significant effect of forest conservation status on forest stand structure. Many forest ecosystem functions depend on structural properties and many forests services such as maintaining biodiversity or wood supply highly depend on stand structure composition and properties. Anthropogenic disturbance like tree removal or fuel gathering by rural communities alters the stand structure over time. Based on results in the forest area with a low impact of humans, stand structure is near to the natural structure. Considering the positive influence of forest enclosing on a reduction of human manipulations and improvement in some valuable stand characteristics, we suggest forest enclosing in the study area. It can be concluded that enclosing would provide an opportunity for ecosystem resilience and contribute to building up the more diverse and heterogeneous structure to conserve yew stands as a rare conifer species in this area.

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