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Research Article

Structural dynamics of deciduous mixed stands in the Hyrcanian forests, northern Iran

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Abstract

Forest structure as an effect of forest dynamics can be used to characterize biophysical processes, biodiversity and ecosystem functions. This study examines the structural components of old-growth forest stands located in the Caspian forests, north of Iran. We measured forest-related attributes in five plots located in the Kheyrud Forest, Mazandaran Province, Iran in 2004 and 2014, respectively. The mean stand density was of 338.6 tree ha^{-1}, the mean volume was of 389.2 m^3 ha^{-1}, and the volume of deadwood accounted for 34.1 m^3 ha^{-1}. The mean stocking volume per hectare was for beech: 3.95; hornbeam: 7.00; oak: 1.39; maple: 0.60 and other species: 2.55 m^3 ha^{-1}. Meanwhile, the mean volume of the felled trees, other cuttings, snags and logs were 31.3, 1.1, 12.6, and 21.5 m^3 ha^{-1}, respectively. The mean abundance of gap size on small (<200 m^2), intermediate (200-500 m^2), and large (>500 m^2) classes were calculated as 53.5, 37.9, and 14.1%, respectively. No significant difference in size gap distribution was detected over 10 years, neither any gap size class. The coarse woody debris (CWD) percentage from total deadwood volume varied from 67% to 93%, whereas the fine woody debris (FWD) amount was estimated ranged between 7 and 33%. No significant differences between 2004 and 2014 was found for CWD and FWD. Comparison of spatial pattern results of tree species in 2004 and 2014 implies that there were no significant changes in the mingling index, uniform angle index, or diameter differentiation at species and stand levels, except oak and maple species that showed a significant change in diameter growing. In other words, despite the harvesting of the trees, spatial pattern indices have not changed significantly. These results indicate the performance of ecological forestry programs by foresters in the Hyrcanian Forest stands and their increasing consideration to the ecological principles of the forest. The results are useful in the sense that they characterize the stand structure components which are fundamental to performing silvicultural treatments based on the emulation of natural forest structural dynamics.

Keywords: Hyrcanian forests; mixed stands; old growth; structural component

Introduction

Traditional silviculture systems such as clear-felling, partial cutting, and shelterwood originated from central Europe and were classified according to the stand and regeneration type (Iovino, 2011; O'Hara, 2016). However, the conventional silviculture practices constraints often overcome their advantages (Boncina, 2011).

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The concept of disturbance-based gap silvicultural systems has been frequently used in recent decades (Ferlich, 2002; O'Hara, 2016; Schütz *et al.*, 2016). Management and protection planning of forest ecosystems is conducted mainly through silvicultural systems (Nagel *et al.,* 2017; Nolet *et al.*, 2017). At this time, the latest forestry patterns were characterized as 'returning to the nature' (Bruchánik, 2006). One of these systems, which is in most harmony with close-to-nature silviculture (CNS) (nature-oriented, continuous cover forestry (CCF), or ecological silviculture (ES)) include the selection system (O'Hara, 2016; Schütz *et al.,* 2016). Currently, the forestry procedures recruitment to preserve biodiversity and forest stand structure is crucial in the context of CNS (Wirth *et al.*, 2009; Keren *et al.*, 2014; Bílek *et al.*, 2016; Nagel *et al.*, 2017). Stand structure is a key element in forest dynamics and productivity (Pretzsch *et al.*, 2018). In even-aged pure forests, stand structure and forest dynamics are described by few stand variables. In complex forests, a more detailed characterization of structure is required to adequately study forest dynamics and productivity, as well as to develop management approaches (Bravo-Oviedo *et al.*, 2018).

A forest stand is a homogeneous part of the forest that differs from other parts of the forest by some of the basic elements (composition of stands, cultivation form, age and thickness structure of trees and stocking). The stand structure indicates the species, tree size distribution, height, diameter, open spaces, habitat trees, and dead trees in the stand (Newton, 2007; Javanmiri Pour *et al.*, 2019). Mixed forest stand is defined as a forest unit, excluding linear formations, where at least two tree species coexist at any developmental stage, sharing common resources (light, water, and/or soil nutrients). The presence of each of the component species is normally quantified as a proportion of the number of stems or of basal area, although volume, biomass, or canopy cover, as well as proportions of occupied stand area may be used for specific objectives. A variety of structures and patterns of mixtures can occur, and the interactions between the component species and their relative proportions may change over time (Bravo-Oviedo *et al.*, 2018).

In turn, stand structure can be considered a biophysical process or a schema for biodiversity and ecosystem functions (Vidal and Renato, 2006; Marinsek and Diaci, 2011). Therefore, the forest structure can assist on revealing the history, function, and forest ecosystem future (Spies, 1998). The forest structure refers to arrangement of various components (Fischer *et al.*, 2013; Auffret *et al.*, 2015; Ahlström, 2016). Therefore, the stand structural components can be the age of the stands (Roessiger *et al.*, 2016), layering structure of forest stands that characterize its structural complexity (Brkaw and Lent, 1999), leaf area index (LAI) (Chen and Chilar, 1995), forest stock (Avery and Burkhart, 2003; Husch *et al.*, 2003; Pretzsch, 2010), stand density - which is usually the number of trees within a definite area (Avery and Burkhart, 2003; Pretzsch, 2010), spatial patterns (Oliver and Larson, 1996; Dale, 2000; Trifković and Yamamoto, 2008; Feoli and Oorlci, 2012) or standing dead trees (snags) and large woody debris (logs) (Franklin *et al.*, 2002; Burrascano, 2008, Javanmiri Pour and Etemad, 2022).

The horizontal spatial pattern of trees is an important attribute of stand structure, which provides an idea of the variation in tree spacing rather than stand density, which represents its average (McElhinny *et al.* 2005). The variation in spacing is frequently described by an aggregation index, which quantifies the degree of clustering in the horizontal arrangement of trees (McElhinny *et al.*, 2005). Three main types of spatial pattern can be defined as (1) regular, (2) random (Poisson) and (3) clumped (aggregated) in varying degrees, depending, in natural forests, on site, species composition, sampling scale and stand age (Szwagrzyk and Czerwczak, 1993; Hanewinkel, 2004; von Oheimb *et al.*, 2005; Fukasawa *et al.*, 2014; Moussaoui *et al.*, 2019).

The quantification of forest stands means the measurement of various structural components by means of different measurement methods for each component (Stiers *et al.*, 2020). Stand structure quantification of deciduous forests in northern Iran has been in the scope of much parallel research (Sefidi *et al.*, 2011; Amiri *et al.*, 2015; Yusefpoor *et al.*, 2016; Sefidi *et al.*, 2016). In a companion study, the characteristics of dead trees in successional stages of Oriental beech in Hyrcanian forests were studied. The dead trees volume mostly exhibited a U-shaped trend (Sefidi and Marvie Mohadjer, 2010). The highest, the least, and, intermediate deadwood volumes (i.e., 51.25, 25.95, and 37.05 m^3ha^{-1}) occur in the late successional, middle successional, and the early successional forest. Another study scrutinized oriental beech stands structure variations through evolutionary phases in northern Iran. Mean volume, stem density, and dead wood volume were quantified at 540 m^3 ha^{-1}, 412 stem ha^{-1}, and 24 m^3 ha^{-1}, respectively (Moridi *et al.*, 2015).

Numerous studies on forest stand fundamentals and assessments on natural forests stands in various regions of the world have been published (e.g., McCarthy and Weetman, 2006; Sapkota *et al.*, 2009; Rugani *et al.*, 2013; Saniga *et al.*, 2014; Pretzsch *et al.*, 2014; Motta *et al.*, 2015). Most of them were dedicated to the stand structure inquiry and fundamental structural essentials, dead wood, forest gap, regeneration processes, forest succession, and disturbance pattern. Nevertheless, few of them focused or quantified the forest stand characteristics in mixed Hornbeam-Beech dominated stands. This is due to the rareness of mixed stands with a high diversity on temperate forests beside forest structure factors abundance. Lately, some researchers have published a number of independent works on pure oriental Beech in the Caspian Forest (Sefidi and Marvi Mohadjer, 2010; Sefidi and Etemad, 2014; Sefidi and Etemad, 2015; Amiri *et al.*, 2015; Moridi *et al.*, 2015) or European beech (*F. sylvatica*) in Europe's forests (Heiri *et al.*, 2009; Marinse and Diaci, 2011, Diaci *et al.*, 2012; Kucbel *et al.*, 2012). So far, no study has been done to monitor the manager's practices on structural variations in the Hyrcanian forests.

Previous work was performed at different temporal and spatial scales in Hyrcanian Forest, and the average volume of dead trees was reported as 19.8 m^3ha^{-1} (Sefidi *et al.*, 2011), 23.6 m^3ha^{-1} (Habashi, 2007), 16.5 m^3ha^{-1} (Zolfaghari *et al.* 2007), 37.6 m^3ha^{-1} (Sefidi and Marvi Mohadjer, 2010) and 45.4 m^3ha^{-1} (Amiri *et al.*, 2015). In a Turkish beech forest, the dead trees amount was assessed as 22.87 m^3ha^{-1} where 42% of them were as log (Aticie *et al.* 2008). In Europe, the mean volume of dead trees has been found at 30-130 m^3ha^{-1} in natural forests (e.g., Korpel, 1995; Kölbel, 1999, Saniga and Schutz, 2001; Von Oheimb *et al.*, 2005).

The latest analyses of the Hyrcanian Forest have concentrated on stand structure variability from the dominated natural pure beech stands. Determining a mixed stand-scale structural component is crucial for the comprehensive understanding of forest structure. Therefore, this study's purpose is to analyse the structural characteristics of mixed stands of oriental beech and hornbeam under disturbance-based silvicultural management such as a selection system. Such research can provide the opportunity to study structural properties in the temperate broadleaved forest ecosystems. In order to test whether low intensity silvicultural interventions into mixed forests characteristic to close-to-nature management practices that mimic the forest processes occurred naturally, we phrased the following two hypotheses: (H1) No statistically significant differences in the size of the structural indices between the two inventories (2004 and 2014) for beech and hornbeam, two very shade-tolerant species. However, we expect that oak and maple, more light-demanding species, to react significantly to the interventions, particularly in the structural indices related to the diameter growth; (H2) artificially created canopy openings by low-intensity interventions within selection system, together with the already existed natural gaps provoked by natural mortality process (senescence and competition) of single trees or few trees groups are quite stable in short time monitoring (no significant differences in the distribution of gaps over 10 years).

Materials and Methods

Site description

Field sampling of this study took place in the "Kheyrud Forest" in northern Iran, which is managed by the University of Tehran for education, research, and conservation, and the sampling area is located at an altitude of 1000-1200 m.a.s.l. (36°27'N to 36°40'N and 51°32'E to 51°43'E), Mazandaran province (Figure 1). The climate is sub-Mediterranean with a mean annual temperature of 9 °C and total annual precipitation of 1380 mm. Average daily temperatures range from a few degrees below 0 °C in December, January, and February to +25 °C during the summer (Sagheb-Talebi *et al.*, 2014). Soils are classified as well-drained forest brown soils (Alfisols) with a soil texture ranging from silt loam to loamy. Carbonate rocks (limestone and dolomite) and their numerous karst forms characterize the topography of the study area: crests, carks in limestone, underground flows, and sinkhole structures. Forests occupy plateaus on moderately inclined slopes, largely free of rocks with limestone bedrock. The study area is dominated by natural forests with native mixed deciduous tree species, including *Fagus orientalis* Lipsky, *Carpinus betulus* L., *Alnus subcordata* C.A. Mey, and *Quercus castaneifolia* C.A. Mey.

Figure 1. Kheyrud study area location in the Hyrcanian Forest, Iran

Data collection

In this study, five 1-ha (100 × 100 m) sample plots were installed for the examination of spatial pattern and the vertical structure (one rectangular plot established in each study site). The method used for plot establishment was from the lowest to the highest point in each stand. After setting the boundaries of plots in the forest, their southwest corner coordinates were recorded by a GPS device in UTM coordinate system. Here, extract coordinates were employed to distance–azimuth (DA) method. Other factors were measured in these plots, and included species, height, and diameter at breast height for all trees. A full tree inventory in the broadleaved temperate forest stands was carried out in 2004 and 2014 (Figure 2). Five study locations (site I to V, accounting for 150 ha) were selected, covering 22.0, 19.0, 47.3, 25.5, and 28.0 ha, respectively. The study was designed as an experiment with five replications in five stands and the dominant species on mentioned sites include beech, hornbeam, and other species. During the field phase of the study, the all trees with a diameter at breast height (DBH) higher than 7.5 cm (class of 10 cm in diameter) were selected, because the counting limit include 10 cm diameter class (Zobeiri, 2000). Totally, there was measured diameter for all trees found over 150 ha one by one. DBH measurements were taken by a caliper to the nearest millimeter.

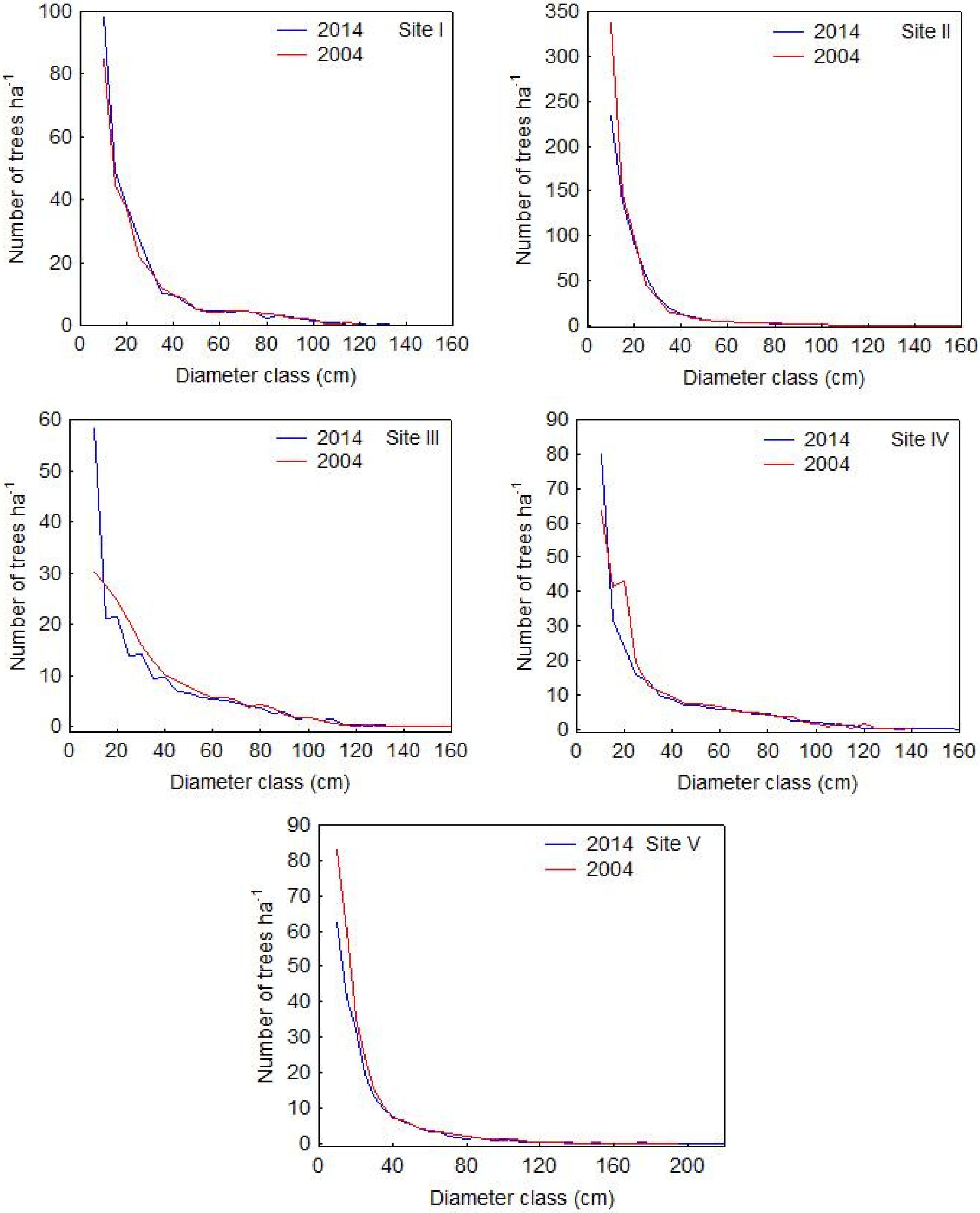


Figure 2. Diameter distributions in all five sites, according to the inventories carried out in 2004 and 2014

In addition, the condition of dead trees was recorded and their volume quantified. The dead wood was divided into snags and logs (i.e. fallen trees). The logs included downed dead trees of more than 10.1 cm in diameter. The dead wood included coarse woody debris (CWD) and fine woody debris (FWD). Coarse woody debris (CWD), synonymous with large woody debris, is a term used to describe wood from dead trees. They include all pieces of wood that are at least 10 cm in diameter and 1 m in length. FWD can mainly include branches of dead trees, attached or not to a fallen dead tree, freshly fallen onto the forest floor from live or dead trees but also terminal stem part of lying deadwood trees. They include all pieces of wood that are less than 10 cm in diameter and 1 m in length (Javanmiri Pour and Etemad, 2022).

The tariff table of Gorazbon region was used to calculate the volume of living trees (Zobeiri, 2000). There is a specific volume for each diameter class in the volume tables. Furthermore, the stock of dead wood (V, m^3) was calculated by the following formulas:

$$\mathbf{V = \frac{g_1+g_2}{2} \times h} \qquad (1)\ \text{(Smalian, 1873)}$$

$$\mathbf{V = g_m \times h} \qquad (2)\ \text{(Röhle and Huber, 1985)}$$

Where g_1 (m^2), g_2 (m^2), g_m (m^2), and h (m) are low, medium and high cross sections, and paraboloid height, respectively.

$$\mathbf{V = \frac{h}{6}(g_1 + 4g_m + g_2)} \qquad (3)\ \text{(Newton, 1997)}$$

where h is neiloid height, g_1 is a low cross-section, g_2 is a high cross-section and g_m is a mid-cross-section (Smallian's and Huber equations were used for trunks that are incomplete paraboloid in appearance. Newton's relation was used to estimate the volume of fallen dead trees).

To calculate the volume of snags (i.e., standing dead wood), the following equation was used (Travaglini and Chirici, 2006).

$$\mathbf{d_{fg} = \frac{d_{1.3}}{h-1.3}} \qquad (4)$$

Where fg is form quotient, d1.3 (m) is diameter at breast height and h (m) is total height.

$$\mathbf{d_m = d_{1.3} - (d_{fg} \times \frac{1}{2})} \qquad (5)$$

Where d_m (m) is diameter in mid-height of the total height of the tree.

Then, the volume is calculated by the Huber's formula. In all five sites, forest management was performed through tree marking and logging (Table 3).

Garmin GPS model 64sx was used to mark all forest gaps all over the five sites. Then, the gap size was estimated by measuring its maximum and minimum diameters. As a general shape gap was similar to an ellipse, so the ellipse area equation was used to estimate the gap area. The canopy gaps were estimated by establishing a pair of vertical lines in the gap (Runkle, 1982).

$$\mathbf{S = \frac{\pi LW}{4}} \qquad (6)$$

Where L (m) is the length of the long line and W (m) is the length of the shorter line.

Data analysis

Four indices were computed to quantify the horizontal (i.e., mixture, spatial pattern) and vertical (i.e., size differentiation, stratification) structure of the structural groups (each reference tree and its neighbours was considered as a structural group). There was used the same number of the nearest neighbours for all such indices (n=3). The mixture index (M) described the proportion of nearest neighbours that belong to the same species as the reference tree (Füldner, 1995). The uniform angle index (W) is used to characterize the spatial distribution of a forest community or of individual tree species within that community based on angles between the focal tree and its nearest neighbours. The value of zero indicates a regular arrangement, 0.50 a random arrangement and 1 designates a clumped arrangement (Zhao *et al.*, 2014). The species mingling index (M) gives the proportion of the three nearest neighbours of the reference tree that belong to the same species as the reference tree (Pommerening, 2002). The reference tree is the tree that is placed in the centre of the structural groups. The diameter differentiation (TD) index reflects the size differences of neighbouring trees scaled between 0 (no size difference) and 1 (high dimensional difference) (Pommerening, 2002). TD index 0-0.3 values indicate a modest differentiation in dimensions; 0.3-0.5 index values designate a moderate differentiation, 0.5 - 0.7 index values demonstrate a significant differentiation, and more than 0.7 index values illustrate a prominent differentiation (i.e., the trees have the smallest DBH is at most 30 % of the size of the great neighbour); (Pommerening, 2002). The DBH-dominance index (U) refers to the proportion of nearest neighbours of a given reference tree that are smaller than the reference tree and describes the relative dominance of a given species in the immediate neighbourhood (Hui *et al.*, 1998). The 0 value indicates that the tree of particular species was the smallest tree in the neighbourhood; a value of 1 indicates that it is the largest tree (Füldner, 1995). The indices, their formulas for computation, and the references that describe the indices in details provided in Table 1.

Table 1. Formulas, references, range of values, and interpretation of each of the four structure indices used in this study

Index	Formula	Explanations	References
Uniform angle index	$W_i = \frac{1}{n}\sum_{j=1}^{n} Vj$	$Vj = \begin{cases} 1 <\propto j \leq\propto 0 \\ 0, otherwise \end{cases}$	Pommerening, 2002
Species mingling	$M_i = \frac{1}{n}\sum_{i=1}^{n} Vj$	$Vj = \begin{cases} 1, species\ j \neq species\ i \\ 0, otherwise \end{cases}$	Füldner, 1995; Aguirre *et al.* (20030
DBH Differentiation	$TD_i = \frac{1}{n}\sum_{j=1}^{n} (1 - rij)$	$rij = \frac{smaller\ DBH}{higher\ DBH}$	Füldner, 1995; Pommerening, 1997, 2002
DBH-dominance	$U_i = \frac{1}{3}\sum_{j=1}^{3} v_{ij}$	$v_{ij} = \begin{bmatrix} 1 \rightarrow DBH_i \geq DBH_j \\ 0 \rightarrow DBH_i < DBH_j \end{bmatrix}$	Hui *et al.* (1998)

Structural data analyses (i.e., mainly the calculation of Uniform angle index, species mingling index, DBH differentiation and DBH-dominance) were carried out by employing the Crancod (version 1.3) software. ANOVA analysis was performed to test the influence of inventory year (2004, 2014) and the size (diameter < 10 cm; diameter > 10 cm) on deadwood dynamics. T-test was applied to investigate the dynamics (2004 vs. 2014) significance in all structural indexes. Finally, in order to test whether there are significant difference in gap size distribution dynamics (2004 vs. 2014) among all three gap size classes (small gap: < 200 m^2; moderate gaps: > 200 m^2 and < 500 m^2; large gaps: >500 m^2), $\chi 2$ test was used. As assumptions required for t-test and ANOVA, the normality of data was tested by Shapiro-Wilk test and homoscedasticity of variances with Levene test. If the required assumptions were not fulfilled, the non-parametric Mann-Whitney U-test was applied. The analyses were done using Statistica 8. software (Statsoft, 2007).

Results

Volume of live and dead trees

The tree density in 2004 varied from the highest value in plot II (808 trees ha^{-1}) to 399 (plot V), 321 (plot I), 267 (plot IV), and to the lowest value in plot III (234 trees ha^{-1}), while in 2014, the tree density increased in all plots, keeping the same plots ranking as in 2004 (873, 418, 354, 281, and 279 trees ha^{-1} in plot II, V, I, IV, and III, respectively) (Table 2). The same pattern of dynamics (higher value in 2014 compared to 2004) was also identified in the stocking volume: 459.0 vs 429.3 m^3 ha^{-1} (plot IV), 411.3 vs 384.3 (plot III), 409.0 vs. 380.0 (plot II), 388.0 vs. 364.0 (plot I), and 276.3 vs. 260.0 m^3 ha^{-1} (plot V), respectively (Table 2). The deadwood amount in 2004 ranged in plot II from 43.2 to 41.7 m^3 ha^{-1} in 2014, from 42.5 to 46.0 in plot III, from 41.6 to 49.8 in plot IV, whereas in plot I and plot V the deadwood quantity but also the changing in deadwood over last 10 years was very low (only a change of 1-1.5 m^3 ha^{-1} reported to a total of 15.5-17.5 m^3 ha^{-1}) (Table 2).

Table 2. Overall stocking volume and dead wood in 2004 and 2014 per sites

Site No.	Site area (ha)	Density (number of trees ha^{-1})		Stocking volume (m^3h^{-1})		Dead trees volume (m^3h^{-1})	
		(2004)	(2014)	2004	2014	2004	2014
Site I	22.00	321	354	364.5	388.0	15.5	17.0
Site II	19.00	808	873	380.0	411.3	43.4	41.7
Site III	47.00	234	281	384.3	409.5	42.5	46.0
Site IV	25.50	267	279	429.3	459.0	41.6	49.8
Site V	28.00	399	418	260.1	276.3	17.5	16.2
Mean	-	405	441	363.6	388.8	32.1	34.1

The mean felled trees stocking volume, other cutting stocking volumes, snag volumes and log volumes accounted for 31.3, 1.1, 12.6 and 21.5 m^3ha^{-1}, respectively (Table 3).

Table 3. Tree marking, other cutting, snag and log volume per hectare and per sites (m^3ha^{-1})

Site No.	Tree marking	Other cutting	Snag	Log
Site I	29.3	1.5	6.3	10.7
Site II	32.2	1.3	15.4	26.2
Site III	27.9	0.4	17.1	29.0
Site IV	31.5	2.1	18.4	31.3
Site V	35.5	0.3	6.0	10.2
Mean	31.3	1.1	12.6	21.5

Forest gap and dead tree

The frequency of <200 m^2 area class was 56 %, 54 %, 45 %, 53 % and 59 % in I, II, III, IV, and V sampling plots, respectively (Figure 3). The intermediate category abundance was calculated as 36%, 38%, 37.5%, 39.5% and 38.5% in I, II, III, IV, and V stands, respectively. The occurrence of >500 m^2 size class includes 8%, 8%, 12.5%, 5.5%, and 3.5% in the I, II, III, IV, and V stands, respectively.

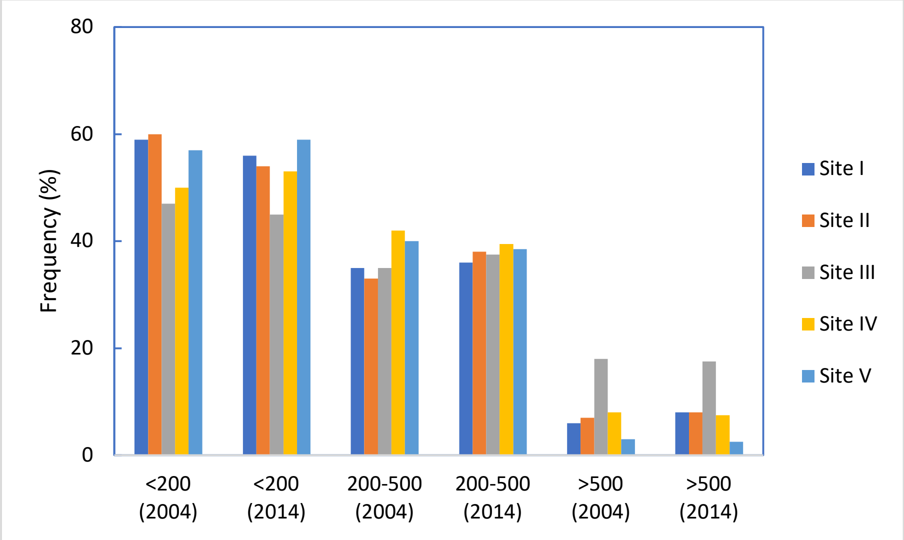


Figure 3. Forest gap rate (%) on various gap sizes (< 200 m^2, 200-500 m^2, > 500 m^2) within sampled sites

No significant difference in size gap distribution was detected over 10 years, neither any gap size class (p>0.05, χ2 test, Figure 4). In the context of the second hypotheses (H2), it can be concluded that the null hypothesis about the absence of statistically significant differences in the distribution of openings could be accepted.

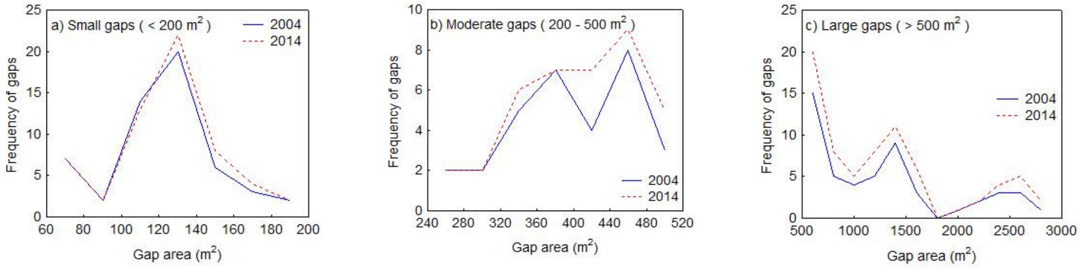


Figure 4. Dynamics of size gap distribution over 10 years for small gaps (a), moderate gaps (b) and large gaps (c). For a certain gap size class, the value included in the figure is the average value for all five stands.

The coarse woody debris (CWD) percentage from total deadwood volume were recorded as 92%, 67%, 93%, 86% and 80% in I, II, III, IV, and V sampling sites, respectively (Figure 5). Furthermore, the fine woody debris (FWD) amount was estimated as 8%, 33%, 7%, 14% and 20% in I, II, III, IV, and V stands, respectively. No significant differences between 2004 and 2014 for CWD and FWD were detected (ANOVA, Scheffe post-hoc test, p > 0.05).

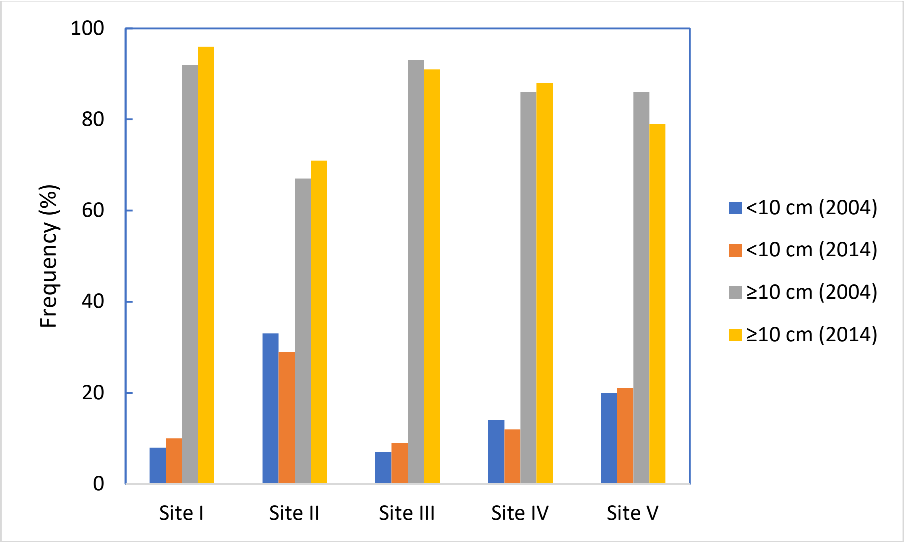
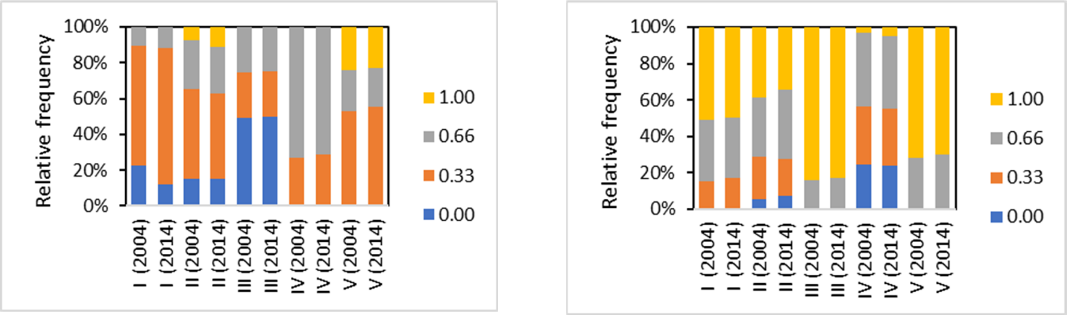


Figure 5. Coarse (diameter ≥ 10 cm) and fine (diameter < 10 cm) woody debris frequency in studied sites

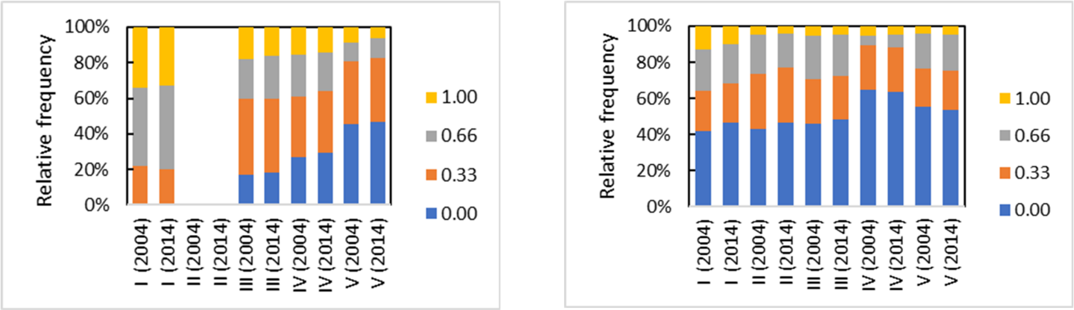
Dynamics in diversity patterns

Species mixture: Mingling index (MI)

The MI values for beech indicated a decrease of mixture degree for all sites (the lowest frequencies occurred in the 0.66 and 1.0 classes, whereas for hornbeam, this decreasing of mixture level is more pronounced). An opposite pattern is meet in the case of oak and maple, the highest values frequencies of MI being occurred in the 0.66 and 1.0 classes (Figure 6).



Oak Maple

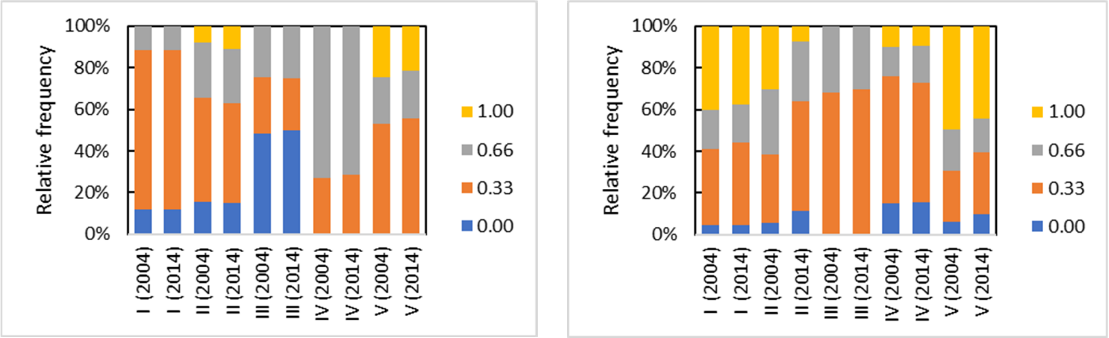


Beech Hornbeam

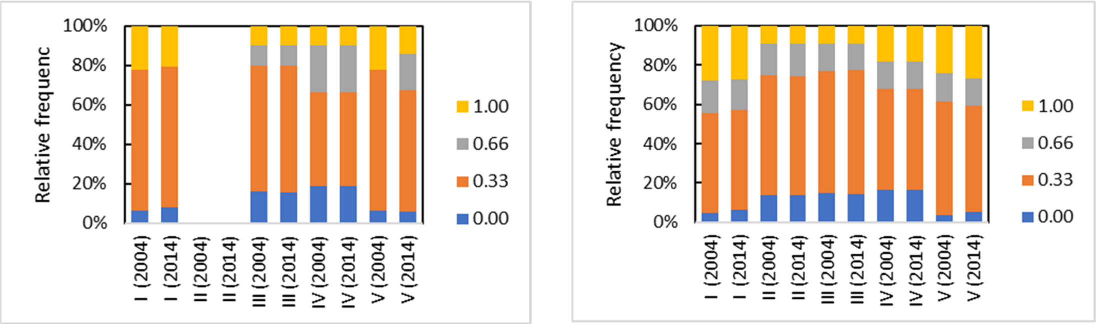
Figure 6. The mingling (M) index distribution for beech, hornbeam, oak, and maple per sites and inventory years

Spatial tree patterns: Uniform angle index (UAI)

If for beech and hornbeam more than 60% of trees are distributed more randomly (UAI value=0.33), tendency of clustering is occurred more frequently for the other two light-demanding species, oak and maple species (UAI=0.66 class for oak and UAI=1.0 class for maple appeared with the highest frequencies) (Figure 7).



Oak Maple

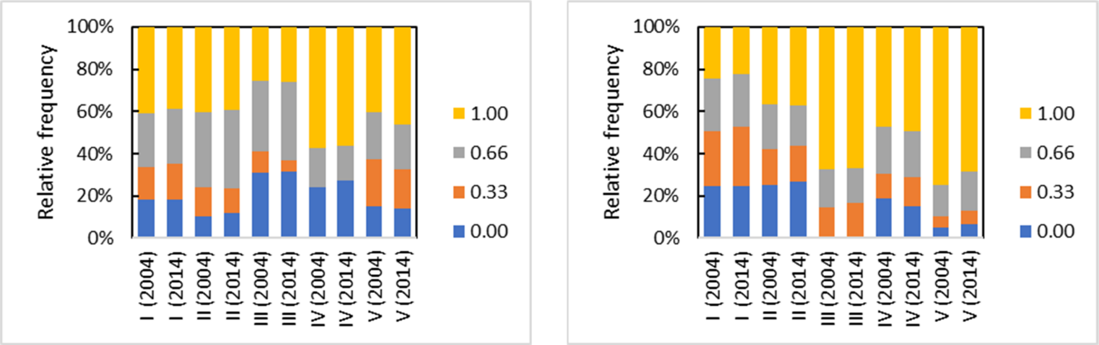


Beech Hornbeam

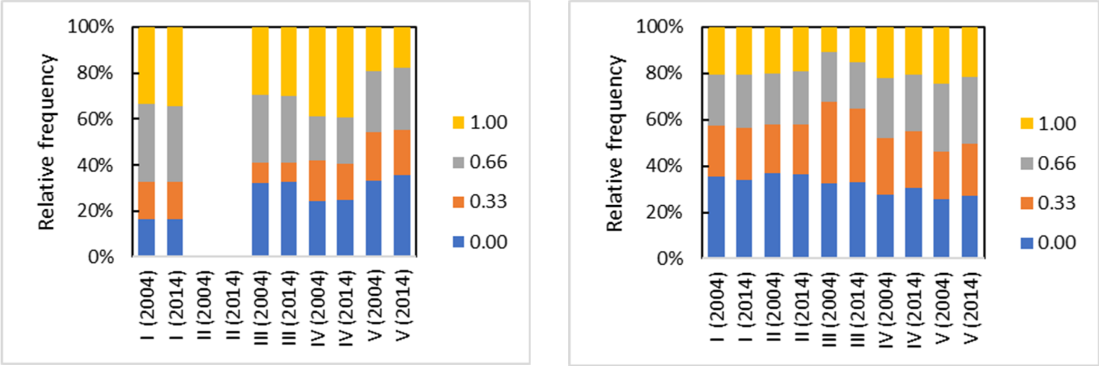
Figure 7. The uniform angle (W) index distribution for beech, hornbeam, oak, and maple per sites and inventory years

DBH-dominance index

Beech and hornbeam appeared with the more or less similar frequency among all DBH-dominance index categories (20-30%, Figure 8), whereas oak and maple presented a clear DBH dominance (a frequency higher than 40%).



Oak Maple

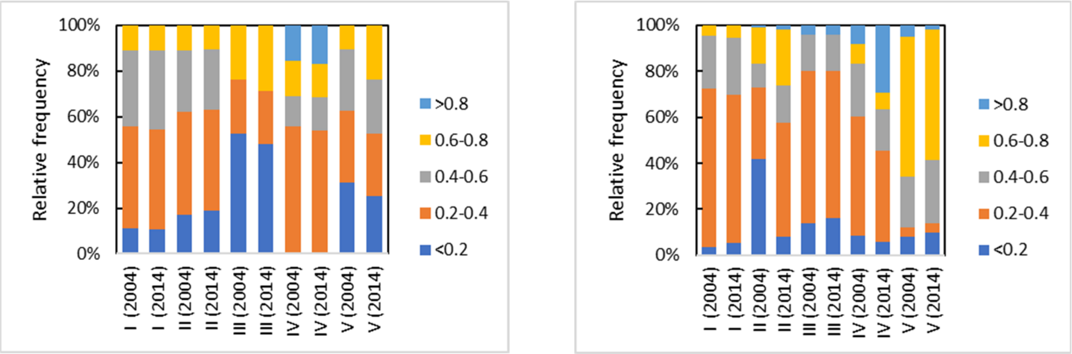


Beech Hornbeam

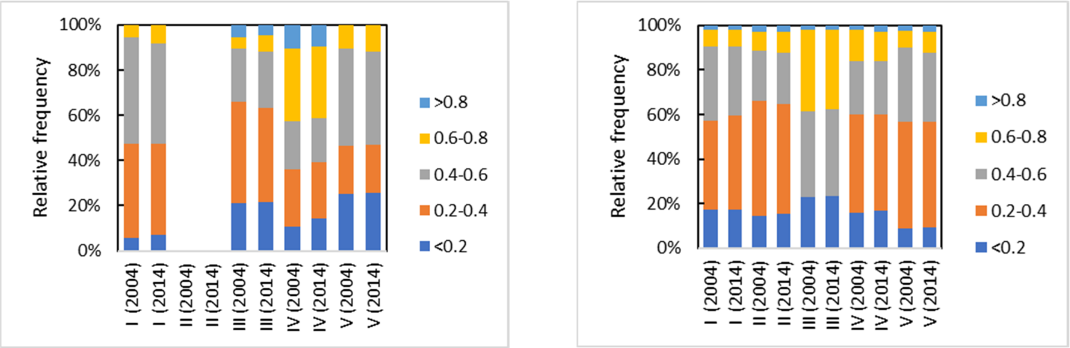
Figure 8. The DBH-dominance (U) index distribution for beech, hornbeam, oak, and maple per sites and inventory years

Diameter differentiation

The highest TD-mean frequencies for beech were found in the 0.4-0.6 class showing a moderate differentiation, while for hornbeam this diameter differentiation was more accentuated (Figure 9). Oak species presented the slightly diameter differentiation, whereas maple showed a strong diameter differentiation (TD>0.7).



Oak Maple



Beech Hornbeam

Figure 9. The diameter differentiation (TD) index distribution for beech, hornbeam, oak, and maple per sites and inventory years

The mean values of mingling index for 2004 did not differ significantly by those of 2014 for all species (independent t-test, p>0.05, Table 4). The uniform angle index difference between the two inventories was significant only for maple (independent t-test, p<0.05, Table 4). DBH-dominance index changed significantly over 10 years for maple, oak and hornbeam, but not for beech (Table 4), while TD-diameter differentiation index increased significantly only for oak species (independent t-test, p<0.05, Table 4).

Table 4. Testing of difference between 2004 and 2014 for mingling index, uniform angle, DBH-dominance and TD-diameter differentiation index

Species	Index	Mean 2004	Mean 2014	N	Difference	Std. Dev. Difference	t	df	P > |t|
Beech	Mingling	0.432	0.453	128	-0.021	0.485	-0.485	127	0.628
	Uniform angle	0.359	0.362	128	-0.003	0.393	-0.074	127	0.941
	DBH-dominance	0.458	0.482	128	-0.024	0.599	-0.442	127	0.658
	TD-diameter differentiation	0.423	0.452	128	-0.029	0.291	-1.133	127	0.258
Hornbeam	Mingling	0.257	0.272	563	-0.015	0.415	-0.855	562	0.392
	Uniform angle	0.403	0.406	563	-0.003	0.411	-0.171	562	0.864
	DBH-dominance	0.302	0.413	563	-0.111	0.535	-4.934	562	0.091
	TD-diameter differentiation	0.368	0.363	563	0.005	0.312	0.420	562	0.674
Maple	Mingling	0.398	0.438	275	-0.040	0.493	-1.343	274	0.180
	Uniform angle	**0.402**	**0.489**	**275**	**-0.087**	**0.404**	**-3.579**	**274**	**0.0004**
	DBH-dominance	**0.381**	**0.178**	**275**	**0.203**	**0.601**	**5.567**	**274**	**0.0000**
	TD-diameter differentiation	0.417	0.416	275	0.001	0.399	-0.008	274	0.993
Oak	Mingling	0.581	0.576	173	0.005	0.522	0.145	172	0.884
	Uniform angle	0.428	0.448	173	-0.020	0.489	-0.561	172	0.575
	DBH-dominance	**0.622**	**0.267**	**173**	**0.355**	**0.586**	**7.952**	**173**	**0.0001**
	TD-diameter differentiation	**0.371**	**0.521**	**173**	**-0.150**	**0.395**	**-4.975**	**173**	**0.0001**

(t – test, bolded values are significant for a p value < 0.05).

Discussion

Our results revealed the mean small, intermediate and large gap sizes abundance consists of 53.4, 32.5 and 14.1 m^2, respectively in 2014. The obtained values in 2014 compared to 2004 did not show a significant difference. The most important reasons for the lack of significant differences in the mentioned period are the absence of a large-scale disturbance occurrence such as storms, fires, landslides and pest infestations in forest stands and as well as light manipulation in forest stands during forest management process based on the natural mechanisms in nature.

Notwithstanding the highest small gaps proportion, their portion of the overall gap size reached hardly 20%, therefore, exhibits the fundamental role of intermediate and large forest gaps on the canopy gap dynamics (Kucbel *et al.*, 2009). The small and intermediate size gaps are favourable for regeneration of contingent species and habitat environments (Sapkota *et al.*, 2009; Bolton and Damato, 2011; Kern *et al.*, 2013). Various species show various responses depending upon the gap size (Lu *et al.*, 2018). Various gaps size represents an influential agent like the light intensity, air humidity, soil biological properties and as well as the type and density of forest regeneration groups. Therefore, in managerial influence, it is necessary to consider the suitability of various gap size to preserve the stand structure in the short term and to achieve the forest stands sustainability in the long duration as well.

Whenever the snag (or part of a snag) lies on the ground, it develops a log (Malone *et al.*, 2009; Lutz *et al.*, 2012). The deadwood average number and volume per hectare usually remain below 5% in many forests comprising Europe and the Caucasus forests except for fewer meddling natural forests and dwindling forests (Christensen *et al.*, 2005). In this context, in previous studies, were reported values of deadwood volume which varied from 6 to 340 m^{3}ha^{-1}, with logs variation including 54% to 73% and snags from 27% to 46%, respectively (e.g., Jaworski *et al.*, 2002; Montford *et al.*, 2002; Christensen *et al.*, 2005; Motta *et al.*, 2006; Mayer and Schmit, 2011; Motta *et al.*, 2015).

The dead tree dynamics, their sizes, and their decay grades are influenced by management practices. The management should be prepared for imitating the fundamental biological cycles in nature, based on harmonious nature methods. Contrary to traditional practices, today, in the ecological forestry concept context, dead trees should be kept in the forest until the break down over time and strengthen the forest soil. The comparison of the dead trees results in 2004 and 2014 illustrations that are followed the mentioned principle by decision makers because of the lack of high differences in measured factors.

In recent years, there has been paid much attention to the spatial pattern as part of the forest structure. Therefore, our results about mingling index indicate the difference between all species, efficiently. The mean UAI of beech, hornbeam, oak, and maple presented the irregular spatial pattern for all species, which reveals that the forest stands stay intact. The outcomes by the mingling index confirm that the maple and oak have interspecific competition, while the beech and hornbeam have intraspecific conflict. Hence, the species composition was affected directly by tree spatial distribution. The beech has a clumped spatial pattern; in contrast, oak showed a random spatial pattern and the ability to group with other species (Pommerening, 2002).

There was determined the distribution pattern of various species in forest communities as a cluster or regular (Manabe *et al.*, 2000). Similarly, other researchers stated that random distributions rarely occur, because trees interact, so these intercommunications clearly affect the spatial pattern characteristics (Manabe *et al.*, 2000). In addition, management manipulation such as thinning or cutting practice leads to the spread of trees (Kint *et al.*, 2000). The spatial analysis pattern definitions display the clump distribution pattern of beech, hornbeam, and alder (Nouri *et al.* 2015). Beech distribution pattern, for instance, was characterized as a cluster arrangement in Shastkola forest on the east of the Hyrcanian region (Habashi *et al.*, 2007). The main reasons for beech cluster dispersal arrangement is correlated with seed weight, shade tolerant trait, and its group regeneration (Habashi *et al.*, 2007; Hasani and Amani, 2010). Another research results on a mixed beech-oak stand apparently indicated that oak has a higher tendency towards a random distribution whereas beech has more drifts to clump dispersal (Pommerening, 2002). Similarly, another researcher advocates that the oak exhibits the random dispersal pattern (Kint, 2000). However, the forest management in combination with ecological factors could affect the spatial pattern (Kint *et al.*, 2000). Typically, managed stands may be thought to have more tendencies towards the regular pattern, since cutting and thinning practices are usually drawn for elite species and not for cluster patterns.

Additionally, structural index of hornbeam, beech, oak, and maple was compared to their neighbours. The DBH-dominance index for the beech, oak, and maple has minor variances and the relative abundance of categories was almost equal by analysing the DBH-dominance diagram in the studied species. However, the reference tree entails higher relative incidence at class 1 for oak and maple than beech. The occurrence of beech at smaller diameters suggests its compatibility with oak as the light-demanding species, similar to the maple as pioneering species in succession (Pommerening, 2002). Similarly, another study suggested that the increase in oak diameter prompts the felling of oversized *Prunus* spp. near oaks, subsequently replaced by younger trees (Kint *et al.*, 2000).

Besides, diameter differentiation results have shown more heterogeneity for beech than its neighbours; hornbeam, oak, and maple had a small heterogeneity. In the temperate forests of northern Iran, the mean diameter differentiations were calculated at 0.45 and 0.37 for beech and oak, respectively (Alijani *et al.* 2012).

In addition, the spatial pattern of the various species certainly changed by management practices such as tree marking and the tree cutting, a process that usually affects ecological issues such as competition. Comparison of spatial pattern results of tree species in 2004 and 2014 implies that there were no significant changes in the mingling index, uniform angle index, or diameter differentiation at species and stand levels, except oak and maple species that showed a significant change in diameter differentiation over last decade (H1 hypothesis is accepted). In other words, despite the harvesting of the trees, spatial pattern indices have not changed significantly. These results indicate the performance of ecological forestry programs by foresters in the Hyrcanian Forest stands and their increasing consideration to the ecological principles of the forest.

Conclusions

Related to the initially formulated two research hypotheses, we would point out that both hypotheses were accepted: low intensity silvicultural interventions within selection system in mixed broadleaves forest stands in Hyrcanian region (northern Iran) did not affect the structural indices over relatively short time period of monitoring (10 years) (H1), but also we would conclude that disturbance regime in such forest ecosystem (including both artificially and naturally created canopy gaps) is quite stable over one decade (H2). However, as a main limitation of our study, we would mention that a longer monitoring time (> 10 years) should be taken into account in future studies as request for a higher robustness of such studies, although all species participated in the current study are known as species that may react in relatively short time to the silvicultural interventions.

Based on the results, the performance of close to nature silviculture and making appropriate management decisions are essential for awareness of the stand structure situation. In managed mixed stands in the north of Iran and Europe, a lot of effort was put forward to bring the stands to their natural structure. We can conclude that various structural features are different in forest habitats. Our study provides a more comprehensive understanding of stand structure foundations. Consequently, it is important to quantify the stands in the real state. On the other hand, the data of each structural pattern needs to be carefully analysed until getting the sustainable forest management nearby the nature silviculture principles. More research is required to compare the structural characteristics with other forest types in northern Iran.

Authors' Contributions

Conceptualization: MJP; Data curation: MJP; Formal analysis: MJP and ICP: Funding acquisition: MJP; Investigation: MJP and VE; Methodology: MJP and VE; Project administration; Resources; Software: MJP and ICP; Supervision; Validation; Visualization; Writing - original draft: MJP with continue inputs from VE and ICP; Writing - review and editing: VE and ICP. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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