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Research Paper

Canopy gaps characteristics of pure and mixed stands in the Hyrcanian forests of north Iran

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Abstract - Canopy gaps play an important role in forest ecology helping to preserve biodiversity, influence nutrient cycles, maintain the complex stand structure, and also they substantially contribute to regeneration of forests. To survey the characteristics of canopy gaps in the Hyrcanian forests of Iran, three main old-growth and intact stands were studied. For each canopy gap, two parameters were measured: the length (L) as the longest distance within the gap and the width (W) as the largest distance perpendicular to the length. The gap maker (DBH≥20 cm) was considered to be a tree from the upper tree layer whose death caused an opening in the canopy. A total of 89 canopy gaps were studied in three old-growth stands (48 gaps in hornbeam-ironwood, 21 in hornbeam, and 19 in beech-hornbeam stands). The given canopy gaps cover 5.4% of the land area with an average of eight gaps per hectare. The mean size of the canopy gaps were 291, 353 and 565m^2 for hornbeam-ironwood, hornbeam, and beech-hornbeam stands, respectively. Frequency distribution of the gap sizes the mentioned three forest stands showed a lognormal distribution. The number of gap makers ranged from one to eight with a median of 4.5. Amongst the studied 261 gap makers in all canopy gaps, 61.2% belonged to hornbeam-ironwood stand. Also, there were canopy gaps formed by one to four gap makers within the three forest types, while gaps formed by five, six and eight gap makers were only observed within hornbeam stand. The results showed that the characteristics of the canopy gaps were different in terms of the composition, complexly of structure, environmental characteristics, size, number and species of gap makers in different forests. As a whole, hornbeam-ironwood stands present in lower altitudes, are more susceptible to wind-throw and create smaller gaps but more gap makers.

Keywords - canopy opening; pure and mixed stands; Hyrcanian ecosystems.

Introduction

Forests are biotic ecosystems on earth and play an important role in the universal nutrient carbon and hydrological cycles. These ecosystems provide habitats for flora and fauna, and as well affect the economy of people around the world (Mohammadi et al. 2010, Stojanova et al. 2010). Among the momentous forest ecosystems in the temperate regions of Iran are the Hyrcanian forests, which comprise various vegetation covers with an area of about 1.9 million hectares. The given forests extend throughout the south coast of the Caspian Sea into the northern part of Iran. Also, These forests grow from the sea level up to an altitude of 2,800 m and encompass different forest types according to their 80 woody species (trees and shrubs) (Sagheb-Talebi et al. 2014). In many forest ecosystems such as the Hyrcanian forests, major disturbance regimes are fundamental in shaping the structure of stands in the context of environmental factors and the present species (Amiri et al. 2015). On the other hand, natural disturbances are a permanent feature of forest ecosystems specifying species' compositions, structures, and processes (Atiwill 1994, McCarthy 2001, Kucbel et al. 2010). These disturbances play a pivotal role in changing forest ecosystems (Kucbel et al. 2010, Amiri et al. 2015, Orman and Dobrowolska 2017, Khodaverdi et al. 2018). They range from small-scale disturbances such as canopy gaps to large-scale disturbances such as strong windstorms, hurricanes, fires, etc. (Pickett and White 1985). Each ecosystem has specific frequencies and types of disturbance regimes based on its climate, soils, vegetation, animals, and other agents (Oliver and Larson 1996). To realize the disturbances, it is necessary to know the frequency, size, severity, and interactions among special disturbance types (Frelich 2002). One of the most important disturbances in forest ecosystems is opening areas called "canopy gaps". Tree-fall gaps, which open areas in the canopy due to the death of one or more trees (Whitmore 1989), are the prevailing form of disturbance. In many forests across the world, canopy gaps play a significant role in the forest regeneration by providing a habitat for recruitment of seedlings and saplings on forest

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floor (Hubbell and Foster 1996). They not only help maintain the characteristic of natural uneven-aged old-growth forests, but also influence on nutrient cycling, soil preservation, and plant species diversity, and also change the micro topography in many forests (Amiri et al. 2015). Over the past few decades, many studies have been conducted to describe gaps characteristics and dynamics, especially in forests of temperate regions. These studies often focus on gap impacts on forest stand structure, nutrient cycling, microclimate, regeneration, restoration, forest management, and other features such as gap size, density, age, mode and frequency of formation, shape, perimeter, and area (McCarthy 2001, Delfan-Abazari et al. 2004, Sagheb-Talebi et al. 2005, Zeibig et al. 2005, Mountford et al. 2006, Imai et al. 2006, Kenderes et al. 2008, Nagel et al. 2010, Sefidi et al. 2011, Muscolo et al. 2014, Amanzadeh et al. 2015, Amiri et al. 2015, Khodaverdi et al. 2018).

The importance of gap dynamics in forest ecosystems was characterized in the early 20th century, and the intensive surveys of gap dynamics features date back to the late 1970s (McCarthy 2001). Since gap dynamics illustrate a crucial procedure in forest stand development, it received much attention during the past several decades. (Denslow 1980, Runkle 1982, Brokaw and Scheiner 1989, Attiwil 1994, Seymour et al. 2002). Canopy gap features have been described for tropical (Van Der Meer and Bongres 1996, Imai et al. 2006), temperate (Abe et al. 1995, Ott and Juday 2002, Amanzadeh et al. 2004, Delfan-Abazari et al. 2004, Sagheb-Talebi et al. 2005, Arrieta and Suarez 2005, Naaf and Walf 2007, Sefidi et al. 2011, Zenner et al. 2019), and boreal forests (Kneeshaw and Bergeron 1998, McCarthy 2001), and are considered as a process capable of forming the structure of forest communities, expanding environmental discontinuity, and increasing a diversity of establishment and growth opportunities for tree species. One of the most important gaps characteristics in the natural forest stands is gap size (Zhang and Zak 1995). Gap size can have a significant effect on stand structure. Many studies have reported gap sizes ranging from 5 m^2 to about 2279 m^2 (Yamamoto 2000, Zeibig et al. 2005, Nagel et al. 2010, Sefidi et al. 2011, Amiri et al. 2015, Orman et al. 2018). Small gaps are originally defined as small openings in the forest created by the death of branches or one or more trees (Watt 1947). Large gaps (>1000 m^2), brought about by through fires, windstorm, or hurricanes have characteristics sufficiently different from small gaps which make comparison difficult. They are also created by a domino effect when big trees fall over other trees (Schliemann and Bockheim 2011).

The aim of the present study is to attain an in-depth understanding of the canopy gaps disturbance regime in Shastkalateh mixed hornbeam-beech an old-growth forest in the Hyrcanian region of north Iran. In particular, we have been interested in examining: (1) the trends of gap characteristics including density, area, perimeter, and size distribution, and (2) the characteristics of gap-makers, especially regarding the representation of hornbeam and beech.

Material and methods

Study area

The Hyrcanian region is a green belt stretching over the northern slopes of Alborz Mountain and covering the southern coast of the Caspian Sea. The zone is rich in flora and includes more than 80 woody species (trees and shrubs) dominated by hardwoods (Sagheb-Talebi et al. 2014). The study was conducted into district no. two of Shastkalateh experimental forest in the south-western part of Gorgan City, Golestan Province, north of Iran. The study area experienced very limited human intervention and disturbance and had no silvicultural activity in the last 100 years. Also, the forest area covers around 1992 ha intact and reserve forest with uneven- aged mixed stands divided into 18 compartments (Fig. 1). It is located between the latitudes 36° 42′ and 36° 43′ N and the longitudes 54° 21′ and 54° 23′ E. The elevation of the study area ranged from 250 to 1935 m asl. The climate is sub-mediterranean and humid with a mean annual temperature of 17.8 °C and mean annual precipitation of 650 mm (Anonymous, 2008). Selected forest communities occupy plateaus or moderately inclined slopes (less than 40%), which are dominated by moderately acidic to alkaline brown forest soils with deep and semi-deep, limestone bedrock, and a surface largely free of rocks. The compartments consist of a natural, mixed, uneven-aged deciduous old-growth forest.

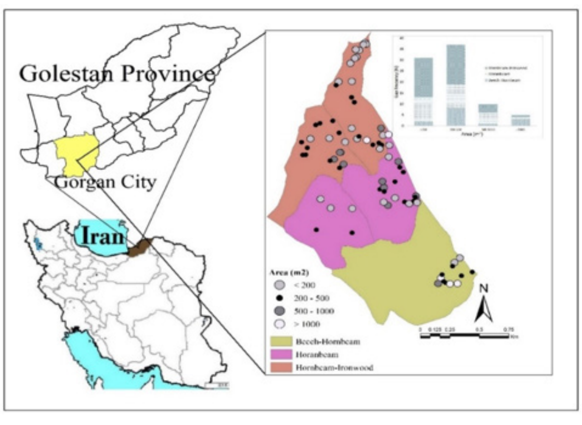

Figure 1 - Study area within the 2 district of the Shastkalateh experimental Forest in northern Iran.

Table 1 - Some of the basic characteristics of the studied forest stands—(1) hornbeam-ironwood, (2) hornbeam and (3) beech-hornbeam.

Forest Stand	Composition of tree species based on number of trees (%)	Area (ha)	Sea level height (m)	Slope (%)
1	hornbeam (56.5), ironwood (32), velvet maple (6), date plum (3.5), beech (2)	65	300–500	5–30
2	hornbeam (88.6), ironwood (7.1), velvet maple (2.5), date plum (1.8)	73	450–700	10–45
3	beech (68.5), hornbeam (23.6), velvet maple (2.1), date plum (1), ironwood (3.8), cappadocian maple (1)	82	670–840	10–50

Oriental beech (*Fagus orientalis* Lipsky), common hornbeam (*Carpinus betulus* L.) and Persian ironwood (*Parrotia persica* C.A.Mey.) are the major species with velvet maple (*Acer velutinum* Boiss.), Cappadocian maple (*Acer cappadocicum* Aureum), date plum (*Diospyros lotus* L.), large-leaved lime (*Tilia platyphyllos* Scop.), wych elm (*Ulmus glabra* Huds.) wild cherry (*Cerasus avium* (L.) Moench), and wild service tree (*Sorbus torminalis* L.) as the less common ones (Sagheb-Talebi et al. 2014).

Field measurement and data analysis

To investigate the characteristics of canopy gaps, three mature and intact stands of broad-leaved species — (1) Hornbeam-Ironwood, (2) Hornbeam and (3) Beech-Hornbeam — were selected in two districts of Shastkalateh forest in Golestan Province of Iran (Table 1). Field inventories were carried out during the summer and autumn 2016. The survey included a total of 89 gaps, with 48 gaps pertaining to hornbeam-ironwood, 21 gaps to hornbeam, and 19 to beech-hornbeam. For the three forest stands, we recorded the types of canopy openings (Runkle 1982). A canopy gap is the area directly under the canopy opening with the border distinguished by the crown projections of trees surrounding the canopy opening. Also, a canopy gap can be defined as an opening in the canopy with at least 20 m^2 that is formed by the mortality of one or more trees from the upper tree layer with DBH ≤20 cm (Amiri et al. 2015). A gap is considered closed and not sampled when the height of regeneration reaches half the height of the gap surrounding trees (Orman and Dobrowolska 2017).

For each canopy gap, two features were measured—the length (L) as the longest distance in the gap, and the width (W) as the largest distance perpendicular to the length. The gap form was considered as the ellipse, and the area of canopy gap was calculated using the formula for an ellipse: $A=\pi LW/4$. Origin of each canopy gap in the study area was based on windthrow. Only dead trees of DBH ≥20 cm were considered as gap makers. In each gap, the species and the number of gap makers were recorded and the mode of mortality (i.e., snag, uprooted or snapped) were identified (Nagel and Svoboda 2008, Petritan et al. 2013, Amiri et al. 2015). The volume of each dead tree (i.e. uprooted, snapped and snags volume), was calculated by Newton's (Harmon Sexton 1996):

$$V = \frac{L(A_b+4A_m+A_t)}{6} \quad (1)$$

Where: V – volume (m^3), L – length, Ab, Am, At – areas of the base, middle and top, respectively.

Also, simple linear regression was used to test the relationship between gap size (area) with gap perimeter and number of gap maker (Sefidi et al. 2011). The regression analyses were performed using SPSS (version, 19).

Results

Canopy gaps

We found 89 gaps in the three forest stands (N=48 in the hornbeam-ironwood stand; N=22 in the hornbeam stand; N=19 in the beech-hornbeam stand), with an average of eight gaps per hectare comprising 5.4% of the land area (Fig. 2). The size of the canopy gaps for the three stands ranged from 38 to 1704 m^2 on average and the median from 470 to 279 m^2, respectively. The most frequent canopy gaps were 100–200 m^2 for hornbeam-ironwood and hornbeam stands and 300 to 400 m^2 for the beech-horn-

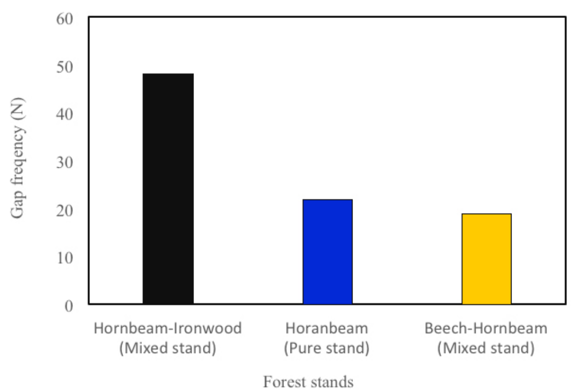

Figure 2 - Study area within the 2 district of the Shastkalateh experimental Forest in northern Iran.

Table 2 - Canopy gap characteristics in three forest stands study (1=Hornbeam-Ironwood, 2=hornbeam, and 3=Beech-Hornbeam).

Forest stand	Gap number	Gap size (m2) mean (min-max)	Std	Perimeter (m) mean (min–max)
1	48	291 (38-1338)	136	72 (28-135)
2	22	353 (71-1256)	232	69 (38-189)
3	19	565 (55-1704)	315	56 (45-174)

beam stand. The mean of the canopy gap size was 291m^2 for hornbeam-ironwood (min. 38 and max 1338 m^2), 353 m^2 for the hornbeam stand (min. 71 and max. 1256 m^2), and 565 m^2 for the beech-hornbeam stand (min. 55 and max. 1704 m^2). Although the largest number of gaps belonged to the hornbeam-ironwood stand, smaller gaps were observed in the same stand compared to the hornbeam and beech-hornbeam stands (Table 2).

The study of the frequency distribution of the canopy gap sizes for all the three forest stands showed a lognormal distribution (with the parameters μ=7.15 and σ=0.53; χ^2=1.89, df=3, and P=0.054) with the hornbeam and beech-hornbeam stands having a sinusoidal graph. The most frequent canopy gaps (62.20%) for the three stands were centralized between <50 and 300 m^2 with the overall maximum in the class from 100 to 200 m^2 (29.26%). However, 31.70% of all the canopy gaps were >300

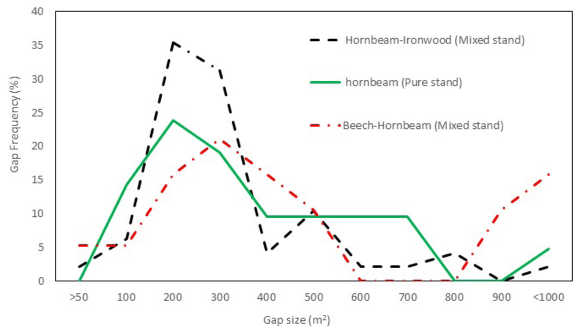

Figure 3 - Frequency of canopy gap according to size classes in the forest stands.

m^2 and <1000 m^2. Also, the results of this research showed that only about 6% canopy gaps were larger than 1000 m^2 (Fig. 3). The area-perimeter relationship for the canopy gaps showed that they became more irregular in shape as their size increased. All the three forest stands had a regression power model in perimeter- to- area ratio (hornbeam stand ($y = 31.964x^{0.6027}$, R^2 = 0.92), beech-hornbeam stand ($y = 35.897x^{0.6219}$ R^2 = 0.84) and hornbeam-ironwood stand ($y = 31.711x^{0.6359}$ R^2 = 0.88)). This shows that the difference in the coefficient of determination of the models is related to tree form and architecture.

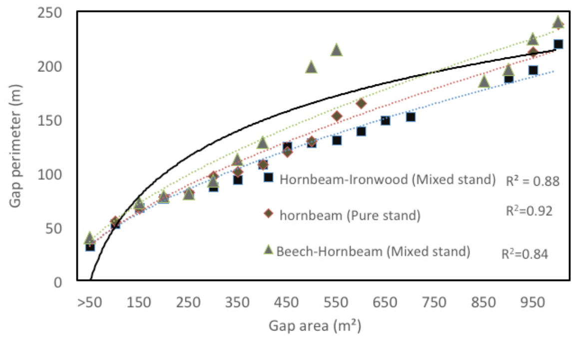

Figure 4 - The gap area– perimeter relationship for three forest stands study: Hornbeam-Ironwood, hornbeam, and Beech-Hornbeam. The dashed line indicates the area-perimeter ratio for a circle.

Also, the perimeter-to-area ratio for gaps ranged from 0.2 to 0.81, and the mean perimeter-to area ratio was 0.23 (Fig. 4).

Gap maker characteristics:

In the three forest stands, most of the canopy gaps were formed by the death of several trees. The number of gap makers ranged from one to eight with a median of 4.5. Figure 5 shows the number of dead wood per gap according to the forest stand. Among all the 261 gap makers in the canopy gaps, 61.2% belonged to the hornbeam-ironwood stand. The beech-hornbeam stand had the lowest number of gap makers (14.6%) among all the canopy gaps (Fig. 5). The hornbeam gap makers in the three stands made for a total of 44.6% (hornbeam-ironwood), 81.2% (hornbeam) and 7% (beech-hornbeam) of all the studied dead wood, respectively.

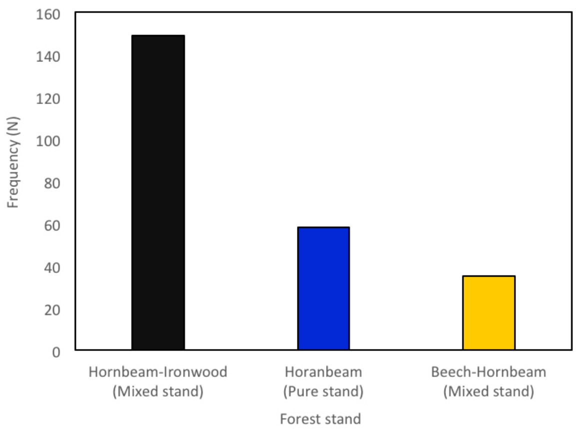

Figure 5 - Number of deadwood (snag and snapped) within canopy gaps according to forest stand (N).

Table 3 - Percentage share of gapmakers by gap number within forest stand.

Tree species	Gap number (N)				
	Hornbeam-ironwood (Mixed stand)	Hornbeam (Pure stand)	Beech-hornbeam (Mixed stand)	Total	
				N	%
Velvet maple	1	1	1	3	3.4
Ironwood	17	2	2	21	23.6
Date-plum	2	1	1	4	4.5
Oriental beech	2	0	10	12	13.5
hornbeam	26	18	5	49	55
Total	48	22	19	89	100

Velvet maple in the three stands had the same contribution to each canopy gap. In no. 1 stand, hornbeam and ironwood species existed were at 26 and 17 canopy gaps of the total of 48 gaps, respectively. Also, in the pure stand (i.e. no. 2 stand) hornbeam was found in 18 (81.8%) of 22 canopy gaps (Table 3).

Of the 148 counted gap makers in the hornbeam-ironwood stand, 44.6% were hornbeam, 41.9% ironwood, and 1.4% beech. Similarly, of the 78 counted gap makers in the pure stand, hornbeam was the most common (81.2%), while ironwood and beech made up for 5.1% and 0% of all the gap makers, respectively (Table 4). Also, in the beech-hornbeam (mixed stand) of the 35 gap makers, 51.5% belonged to beech, while ironwood and hornbeam had the same share (20% of the total gap makers). Velvet maple was less abundant among the gap makers, accounting for only 2%, 3.4%, and 5.7% of all the gap makers in stands 1, 2 and 3, respectively. As for the volume, hornbeam had the highest volume in two hornbeam-ironwood and hornbeam stands with 65.5% and 92.7% of the total volume of the gap maker. In the beech-hornbeam stand, the largest amount was allocated to beech (67.6%) (Table 4).

Regarding the number of gap makers per gap in the three forest stands (Fig. 6), the most common were gaps with two and three gap makers (Each 24.4%). Approximately, two-thirds of the recorded gaps (68.3%) were formed by 1, 2, and 3 gap makers. Gaps with seven and eight gap makers were rare (less than 4%). The results indicated a positive linear relationship between the gap size and the number of gap makers for the canopy gaps in the three forest stands. Gaps formed by seven and eight gap makers comprised about 3.65%. There were canopy gaps formed by one, two, three, and four gap makers in the three forest stands, while gaps formed by five, six, and eight gap makers were only found in the hornbeam stand. No gap was formed by ≥5 gap makers in the beech-hornbeam stand (Fig. 6).

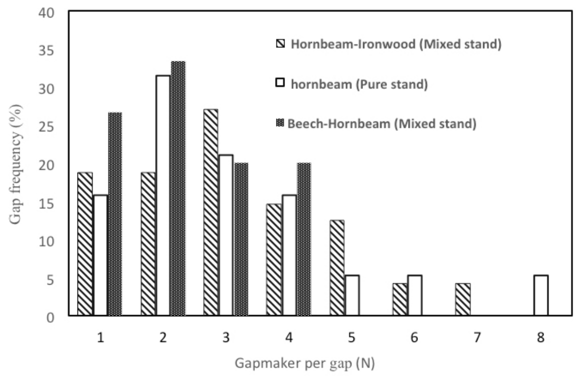

Figure 6 - Gap frequency according to number of gapmakers per gap.

Table 4 - Percentage share of gapmakers by species within forest stands.

Tree species Gap maker (DBH>20cm)	Forest stand											
	Hornbeam-Ironwood (Mixed stand)				Hornbeam (Pure stand)				Beech-Hornbeam (Mixed stand)			
	N. of trees	%	Volume	%	N. of trees	%	Volume	%	N. of trees	%	Volume	%
Velvet maple	3	2	20	2.7	2	3.4	14.3	3.8	2	5.7	11.6	3.5
Ironwood	62	41.9	200	27.6	3	5.1	8	2.2	7	20	25.3	7.6
Date-plum	15	10.1	18.9	2.7	6	10.3	4.9	1.3	1	2.8	0.6	0.2
Oriental beech	2	1.4	11	1.5	0	0	0	0	18	51.5	225.3	67.6
hornbeam	66	44.6	475.1	65.5	67	81.2	345.9	92.7	7	20	70.6	21.1
Total	148	100	725	100	78	100	373.1	100	35	100	333.4	100

Discussion

Most forest ecosystems, especially old-growth forests in the temperate regions, are subjected to natural disturbances. These disturbances play an important role in the dynamics of forest ecosystem, including determining the species' composition, structure, process, and status of regeneration (McCarthy 2001, Kucbel et al. 2010, Amiri et al. 2015). Across the Hyrcanian deciduous forest region, most forest lands are composed of mixed hardwood species. Some recent studies analysed the gap characteristics in different Hyrcanian forests in northern Iran (Delfan-Abazari et al. 2004, Sagheb-Talebi et al. 2005, Sefidi et al. 2011, Amiri et al. 2015), but no such research has been carried out on mixed broad-leaf stands in the district no. 2 of Shastkalateh forest. Undoubtedly, forest disturbance dynamics differ between different types of old-growth forests. This study revealed the characteristics of canopy gaps in two mixed and one pure hardwood old-growth forest.

The results revealed that the canopy gap sizes in the three stands varied between 38 m^2 and 1704 m^2. Other studies in the Hyrcanian forests reported different gap sizes ranging from 40 to 622 m^2 in district one of Shastkaleteh forest (Amiri et al. 2015), 80 to 1230 m^2 in Golband forest, 89 to 2279 m^2 in Asalem forest (Amanzadeh et al. 2004), 63 to 1383 m^2 in the Mazandaran mixed beech forest (Sagheb-Talebi et al. 2005), and 34 to 579 m^2 in Kheyroud, Noushar (Mataji et al. 2007). The totall area of canopy gaps was 29117 m^2, which nearly covered 5.4% of the three forest stands. Of the total area of 29117 m^2, the proportions of hornbeam-ironwood, hornbeam, and beech-hornbeam stands were 47.9%, 23%, and 29.1%, respectively. The given proportions generally corresponded to the results from Hyrcanian forests in northern Iran (Delfan-Abazari et al. 2004, Mataji et al. 2007, Sefidi et al. 2011, Amanzadeh et al. 2015, Amiri et al. 2015). When comparing the proportion area of canopy gaps studied in this research with those of the old-growth forests of less resemblance tree species compositions in Europe (Zeibig et al. 2005, Nagel and Svoboda 2008, Kenderes et al. 2008, Orman and Dobrowolska 2017), North America (Runkle 1982) and Japan (Yamamoto and Nishimura 1999) which range frome 11-19%, the value reported in our study stands (5.4%) lies close to that of the Hyrcanian forests (up to 9%). However, compared to the other mixed forest stands in America, Central Europe, and Japan, the reported values were at the lower end. Also, Zeibig et al. (2005) showed a 5.6% gap proportion and an average gap size of 137 m^2 in Slovenia forests. The size of gaps is obviously nearly related to the number of trees involved in its creation. Nevertheless, differences in the definition of canopy gaps or in the methods used for canopy gap sampling may also result in different estimations of gap area (Yamamoto et al. 2011, Orman and Dobrowolska 2017). A smaller minimum gap size threshold adopted in gap measurements usually results in a higher gap fraction (Garbarino et al. 2012). Since the minimum gap size threshold can significantly vary among studies (Amiri et al. 2015, Orman and Dobrowolska 2017), the comparison of gap areas among different studies need to be viewed with some precaution (Orman and Dobrowolska 2017).

Most of the canopy gaps in all the three stands in the present study were smaller than 300 m^2 (62.20%), and the gap number decreased with increasing gap size (Fig 4). Alike results were reported from pure beech and mixed beech-hornbeam stands in Keyroud and Shastkalateh forests in Hyrcanian region (Sefidi et al. 2011, Amiri et al. 2015). But, Delfan-Abazari et al. (2004) found that the area of most of the gaps ranged between 300 to 500 m^2 in Kelardasht forest.

We found that the lognormal distribution corresponded to the frequency distribution of the canopy gap size in all the three stands. Most authors have reported that the frequency distributions of gap sizes follow a lognormal in different forest types across the world (Zeibig et al. 2005, Nagel and Svoboda 2008, Kucbel et al. 2010, Sefidi et al. 2011, Petritan et al. 2013, Orman and Dobroloska 2017, Zenner et al. 2019). However, some other researchers have reported a negative exponential form (Nagel and Svoboda 2008); however, many other studies of mixed beech forests in Europe have indicated that episodic intensive disturbances caused by wind, fire, and/or snow play an important role in the dynamics of these forests (Firm et al. 2009, Nagel et al. 2010, Kulakowski et al. 2017, Orman and Dobroloska 2017). Although, our study and others have indicated that such events are more likely to be caused by longevity, wind, and recent fires in Hyrcanian forests.

The results from the present study of the three forest types have authenticated this typical feature as well (i.e. the specific dominance of small gaps (100–400 m^2)) and a potent decrease in gap frequency with an increase in gap size (Fig. 3). This particular feature is more obvious in the hornbeam-ironwood stand than in the two others. With increasing canopy gap sizes, their frequency decreases sharply. Similar to other studies in Hyrcanian forests, small gaps comprise a relatively high proportion (62.2%) of the total gap area (Fig. 2), and thus their significance in regeneration dynamics is higher than one would expect considering their low frequency.

We found that most of the gaps were formed caused by one to four tree-fall events in all the three stands (84.2%) and identified that no gaps were formed by five or more gap makers in the beech-hornbeam stand. But we found that only one gap was formed by eight gap makers in the hornbeam stand. Differences in the number and composition of species, the stand structure, biomass arrangement, and the DBH of tree distribution in each stand can lead to differences in the number and types of gap makers forming the canopy gaps. On the other hand, researches on pure and mixed Hyrcanian forests have indicated that most gaps are formed as a result of single tree-fall (the single tree gap proportion is more than 50% of all gaps) (Sefidi et al. 2011, Amiri et al. 2015) and two tree-fall events (Delfan-Abazari et al. 2004, Sagheb-Talebi et al. 2005).

For the distribution of gap maker numbers per gap, some investigations have reported a reverse J-shaped form, i.e. the maximum frequency of single tree gaps (Yamamoto 2000, Mataji et al. 2007, Kucbel et al. 2010, Sefidi et al. 2011, Amiri et al. 2015). This type of distribution was also observed in our study (Fig. 3); however, gaps with one gap maker made up for only 19.5% in all the three stands, which is the lowest value recorded thus far for mixed hardwood dominated forests in the Hyrcanian region of northern Iran (Fig. 6). When we compared the distribution of gap makers per canopy gap with other reports, we found that the presence of one deadwood in each gap was an exception in our study. Even this condition was evident in all the three stands i.e., hornbeam-ironwood, hornbeam, and beech-hornbeam stands.

Conclusion

Canopy gap features are considerably related to forest composition and stand structure. Most natural, small-scale disturbances are so well integrated into forest communities' dynamics that they are considered as the keystone processes for maintaining the health or entirety of forest ecosystems. The composition of species in stand structure and canopy gap environments is a good predictor of future composition in forests dominated by gap-scale disturbance regimes. In the present study, hornbeam (*Carpinus betulus* L.) was the most important gap maker in all canopy gaps, whereas Oriental beech (*Fagus orientalis* Lipsky) was the most dominant gap maker only in beech-hornbeam stand occurring in less than 3% of the gaps in other stands. In the three forest stands, most canopy gaps were small and medium, and the gap area did not exceed a few percent, while in other studies, the gap fraction was greater than that of our study. Nevertheless, there are a few large gaps in the study area, especially in beech-hornbeam stand. The gap number decreased with increasing gap size in the stands. Beech did not contribute much to gap size compared with hornbeam. The area-perimeter relationship for the canopy gaps showed that they become more irregular in shape as their size increases. The results also confirmed a positive linear relationship between the gap size and the number of gap makers for the canopy gaps in the three forest stands. Gaps formed by seven and eight gap makers comprised about 3.6%. Canopy gaps formed by five, six and eight gap makers were only found in the hornbeam stand, while that formed by one, two, three, and four gap makers were more prevalent in the three forest types.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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