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Canopy gaps characteristics and structural dynamics in a natural unmanaged oriental beech (*Fagus orientalis* Lipsky) stand in the north of Iran

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ABSTRACT

Canopy gaps are one of the most important structural features of forest ecosystems, and studying them can have useful results and implications for forest management. The aim of this study was to investigate the characteristics and regeneration within canopy gaps in an intact beech stand in Shastkalateh experimental forest of Hyrcanian region, north of Iran. All canopy gaps and related forest parameters were measured within a permanent plot of 16 ha. Then, 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. Considering the composition of the forest, the dominant tree species was oriental beech with 36.3% of the stem number and 56.6% of the stand volume. Totally, 54 canopy gaps were identified which covered about 5% of the forest area. An average of 4.32 gaps.ha^{-1} existed in the permanent plot and gap sizes varied from 48.3 to 622.7 m^2. Over three-quarters (77.7%) of canopy gaps were smaller than ≤200 m^2 and also over half of the gaps (53%) were formed by a single tree-fall event. The beech made up 52% of gap makers and 23.4% of gap fillers and also had the second largest proportion on standing deadwood of gap maker in the study area, while velvet maple was the most frequent gap filler in approximately 30% of the gaps. Despite the high frequency of small gaps 100 m^2, their proportion of the overall gap area reached only 25%, suggesting the important role of intermediate and large gaps in the gap dynamics. Considering the recent occurring disturbances in the Hyrcanian forests, the study analyzed the main characteristics of disturbance regime with the emphasis on the role of wind and longevity of trees. In general, findings of this study showed that creating small and average gaps in intact beech forests could be based on natural disturbance regimes, and suitable conditions provides for successful regeneration of beech forests in close to nature silviculture.

Key words: Canopy gap, Oriental beech, Permanent Plot, Hyrcanain forests

INTRODUCTION

Forests dominated by oriental beech (*Fagus orientalis* Lipsky) as a major species are one of the most widespread and abundant vegetation types in the Hyrcanian Forest (Resaneh *et al.*, 2000; Sagheb-Talebi & Schütz, 2002; Sagheb-Talebi *et al.*, 2004). On the other hand, intact oriental beech stands provide a unique opportunity to study the disturbance regimes of forest ecosystems without human influence (Sefidi *et al.*, 2011). In many forest ecosystems, major disturbances are pivotal in controlling the structure of stands within the context set by environmental factors and the present species (White 1979; Pickett *et al.*, 1989; Wimberly & Spies, 2000). Disturbance is a permanent feature of forest ecosystems, determining species' composition, structure and process (Atiwill, 1994; Ulanova, 2000; McCarthy, 2001; Kucbel *et al.*, 2010) and it plays a crucial role in the forest ecosystem dynamics (Kucbel *et al.*, 2010). Disturbance events range from the small scale of single tree-falls or crown-breaks to the large-scale caused by e.g., catastrophic windstorms. One of the most important disturbances in forest ecosystems is opening areas called "canopy gap". Canopy gaps play an important role in the regeneration of forest by providing habitat for regenerating seedlings and saplings in the forest floor (Hubbell & Foster, 1996). In many forests throughout the world, tree-fall gaps, opening areas in the canopy caused by the death of one or more trees (Whitmore, 1989), are the dominant form of disturbance. These gaps not only help maintain the characteristic uneven-aged nature of late successional forests, but they also influence nutrient cycling, preserve soil and plant species diversity, and change the microtopography in many forests. Windthrow gaps have been documented in a variety of ecosystems on every continent. Forest gaps have also been termed nutrient "hot spots" because they tend to be areas with high rates of decomposition and mineralization, leading to increased levels of nutrients (Poulson & Platt, 1966; Collins & Pickett, 1988; Denslow *et al.* 1998; Ritter, 2005; Scharenbroch & Bockheim, 2007). Thus, gaps play an important role in the overall biogeochemistry of forest systems. Over the last 30 years, numerous studies have been conducted describing gap dynamics (Denslow, 1987; Yamamoto, 1992; Kuuluvainen *et al.* 1998; Yamamoto, 2000; McCarthy, 2001; Delfan-Abazari *et al*., 2004; Sagheb-Talebi *et al*., 2005; Sefidi *et al*., 2011, Parhizkar *et al*., 2011). These studies focus on gap impacts on forest structure, nutrient cycling, microclimate, regeneration, restoration and forest management. Although there is extensive literature on gap dynamics, it is often hard for managers to interpret results due to inconsistent methods. In shaded understory of forests, many suppressed seedlings and saplings wait for many years for the appearance of a canopy gap (Abe *et al.,* 1995; Hubbell & Foster, 1996; Forget, 1997; Ashton, 1998; Van Der Meer *et al*., 1998). Therefore, forest regeneration processes frequently depend on the natural disturbance regimes (Whitmore, 1989). In fact, canopy disturbances have a major influence in forest communities' structure and organization, since gaps formed by disturbances influence the germination, growth and survival of tree seedlings. The response of trees to disturbance depends on the type of species regeneration and on gap features including dimension, age, morphology, mode and frequency of formation (Abe *et al.,* 1995; Van Der Meer *et al.,* 1998; Yamamoto & Nishimura, 1999; Imai *et al.,* 2006). Importance of gap dynamics in forest ecosystems was discovered in the early 20th century, and intensive investigation of gap dynamic features dates back to the late 1970s (McCarthy, 2001). Gap formation changes the amount of total incident light reaching the ground level and influences nutrient and moisture availability (Denslow & Spies, 1990; McCarthy, 2001; Ritter, 2005; Mihok *et al.,* 2005; Galhidy *et al.,* 2006), providing potential establishment sites for regeneration. Since gap dynamic is recognized as a crucial process in forest stand development, it has received much attention during the last several decades (Denslow, 1980; Runkle, 1982; White & Pickett, 1985; Runkle & Yetter, 1987; Brokaw & Scheiner, 1989; Spies & Franklin, 1989; Attiwil, 1994; Seymour *et al.,* 2002). Gap dynamics have been described in tropical (Van Der Meer & Bongres, 1996; Carvalho *et al*., 2000; Imai *et al*., 2006), temperate (Abe *et al*., 1995; Yamamoto, 1996; Coates, 2000; Choi *et al.,* 2001; Ott & Juday, 2002; Gagnon *et al.,* 2004; Amanzadeh *et al.,* 2004; Delfan-Abazari *et al.,* 2004; Sagheb-Talebi *et al.,* 2005; Arrieta & Suarez, 2005; Naaf & Walf, 2007; Shabani *et al*., 2011; Sefidi *et al*., 2011) and boreal forests (Kneeshaw & Bergeron, 1998; Drobyshev, 2001; McCarthy, 2001, Table 1), and is considered a process capable of shaping the structure of plant communities, in expanding environmental heterogeneity in space and time, in developing a diversity of establishment and growth chances for tree species. Differences in species shade tolerance levels may determine the ability of immature individuals to grow and survive in gaps of different sizes (Carvalho *et* al., 2000; Myers et al., 2000; Schumann et al., 2003; Imai et al., 2006). Gap size is an important characteristic in natural forests and it can strongly influence vegetation growth and nutrient cycling (Zhang & Zak, 1995; Gray et al., 2002; Muscolo et al., 2007). In many studies, gaps ranging from 5 to about 2279 m^2 have been reported (Table 1). Small gaps are originally defined to describe small openings in the forest and are created by the death of branches or one or more trees (Watt, 1947). Large gaps (>1000 m^2), created through fires, tornadoes, downdrafts, or hurricanes, have characteristics sufficiently different from small gaps which makes comparison difficult (Schliemann & Bockheim, 2011) or are created by domino effect when big trees fall over other trees. In particular, very large openings have reduced shading from surrounding trees and consequently have higher solar radiation and soil temperature than small openings (Zhang & Zak, 1995; Gary et al., 2002; Muscolo et al., 2007). In this study, we have examined stand structural and gap characteristics of tree species in old-growth oriental beech stands of the Hyrcanian forests, north of Iran. Specific objectives were to examine: i) stand structure , ii) to examine trends in gap characteristics (gap area, gap size, gap density, gapmaker traits, and number of gap makers), iii) conditions and state regeneration within canopy gaps in the permanent plot in size of 16 ha.

MATERIALS AND METHODS

This study is carried out in the 79 ha natural unlogged oriental beech (*Fagus orientalis*) stand in compartment 32, district 1, located at Shast Kalateh Forest in the Eastern Caspian Region, North of Iran on 36° 43′ 27″ N, 54° 24′ 57″ E. A general view and location of the study area is given in Fig. 1. Elevation of the study area varies from 820 to 960 m a.s.l., with an average monthly temperature of 15.4 °C, with maximum and minimum temperature in July (28.7 °C) and in February (8.71°C), respectively. Mean annual precipitation is 650 mm. According to the De Martonne and Emberger classifications, the climate of the study area is cold and wet, having a temperate summer with short dry season. Stand total height is about 30m and the canopy cover varies between 60 and 100 percent (Habashi et al. 2007). Soil texture is loam to clay-loam with a pH of 5.5 and it is classified as a forest brown soil. Mean stand density and standing volume are 235 ha^{-1} and 463 $m^3.ha^{-1}$, respectively (Anon, 1995 & 2008). The compartment consists of a natural, mixed, uneven-aged deciduous old-growth forest dominated by shade-tolerant Oriental beech with minor components of other broad-leaved species including hornbeam (*Carpinus betulus* L.), velvet and cappadocian maple (Acer velutinum Boiss. and *Acer cappadocicum*), Caucasian alder (*Alnus subcordata*), ironwood (*Parrotia persica*), date plum (*Diospyrus lotus*) and elm (*Ulmus glabra* Huds.). The compartment experienced very limited human intervention and disturbance and had no silvicultural activity in the last 50 years since forest management plans started in Iran. Therefore, this stand could be regarded as an example of an intact and unmanaged natural forest (Hanashi et al., 2007; Anon, 2008).

Field measurment and data analysis

The total surface of compartment 32 is 79 ha and we selected 16ha (400 × 400 m) as a permanent research plot in summer 2011. The location of the plot was selected to satisfy the following conditions: i) the permanent research plot should be placed in the natural oriental beech stand without human influence, and ii) the permanent plot should be homogenous regarding the slope and aspect. Then, the permanent plot was divided into 64 subplots (50 × 50 m), where all individuals of natural regeneration and understory trees of DBH ≥ 7.5 cm were counted within subplots (Delfan-Abazari et al., 2004; Sagheb-Talebi et al., 2005; Habashi et al., 2007). Moreover, on the entire permanent research plot, all living trees with diameter at breast height (DBH) ≥ 7.5 cm, standing deadwood (snags) and fallen deadwood (logs) were measured (Lertzman, 1992; Habashi et al., 2007). The threshold values for snags was the DBH ≥ 7.5 cm and the height > 1.30 m and for logs the small-end diameter ≥ 7.5 cm and length more than 1.30 m. For the living stems and snags the tree species, DBH and only for snags also the height was measured. Tree species, DBH, small- and large-end diameter, total length and the exact location on the sample plot were identified for the logs. On the 16ha permanent research plot, we recorded type of canopy openings—canopy gaps (Runkle, 1982). Canopy gap was the area directly under the canopy opening with the border defined by the crown projections of trees surrounding this canopy opening. When trees within the gap reached the base of canopy of the surrounding forest, a gap was considered closed and not sampled. Canopy gap was defined as an opening in the canopy with the size at least 40 m^2 that was formed by the mortality of one or more trees from the upper tree layer (with DBH ≤ 20 cm), and where the standing or lying remnants of the gap maker were detectable.

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. Gap form was considered as ellipse and the area of canopy gap was calculated using the formula for an ellipse: $A=\pi LW/4$, Gap maker was considered to be a tree from the upper tree layer whose death caused an opening in the canopy. On the other hand, Gap makers were characterized with the following descriptors: type (snapped, root-thrown, dead standing, and leaning), species, and diameter at breast height. The number of gap makers for each gap was recorded, and the tree species and the DBH were identified for each gapmarker as well. Regeneration (gap filler) was sampled within all gaps with seedling (< 1.30 m tall) and sapling according to diameter classes (DBH: ≤ 2.5, 2.5 - 7.5 and 7.5 - 12.5) counted, identified by species, and measured for height and diameter at breast height (Delfan-Abazari *et al.*, 2004).In all gaps "definitive gap fillers" were measured (Sefidi *et al.*, 2011). Additionally, we selected the gap filler most likely to replace each gap maker. These definitive gap fillers were chosen based upon their height, location, and a visual assessment of their overall condition (Lertzman, 1992).

In most cases, we could easily designate the definitive gap fillers because they were considerably taller than other gap fillers, and they often showed a height growth release in response to gap formation that was easily seen in the field, especially for beech and hornbeam. Most definitive gap fillers in this study were pole-sized trees with DBH 7.5 - 12.5 cm and 8 - 15 m tall.

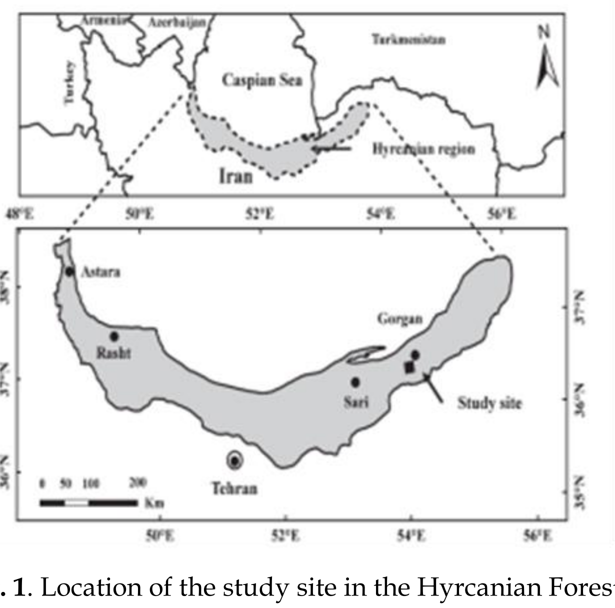

Fig. 1. Location of the study site in the Hyrcanian Forest.

Table 1. Comparison of forest stand and canopy gaps characteristics in differences studies.

Location	Forest cover type (species)	Forest age (year)	Canopy gap size [a] (m^2)	References
Germany	*Fagus sylvatica*	Old growth	116 – 1410	Naaf and Wulf (2007)
Japan	*Fagus crenata*	–[b]	<100 – 1200	Henbo *et al.* (2004)
Chile	*Nothofagus pumilio*	Old growth	50 – 500	Fajardo & De Graaf (2004)
Slovakia (Western Carpathians)	*Fagus sylvatica* (beech–dominant)	Old growth	Canopy gap 5-568 Expanded gap 66 - 1367	Kucbel *et al.,* (2010)
Iran, Asalem	*Fagus orientalis*	Multi age	89 - 2279	Amanzadeh *et al.,* (2004)
Iran, Kelardasht,	*Fagus orientalis*	Multi age	25 - 1098 (550)	Delfan-Abazari *et al.,* (2004)
Iran	*Fagus orientalis*	Multi age	34- 597 (210)a	Mataji *et al.,* (2008)
Iran, Lalis	*Fagus orientalis* (mixed beech stand)	Multi age	<200->600	Shabani *et al.,* (2011)
Iran, Kheyrud-Kenar	*Fagus orientalis* (mixed beech stand)	Old growth	19.6 - 1250 (178)	Sefidi *et al.,* (2011)
Iran, Gorgan	Mixed beech stand	Old growth	48.6 - 622.5 (147.5)	This work

a. Mean in parentheses
b. No data available

RESULTS

Stand structure and composition

The mean density and volume of the studied permanent research plot were 287 Nha^{-1} and $472m^3ha^{-1}$, respectively. Dominant tree species was beech with a proportion of 40% in stem number and which was only counted for 55.8 % of standing volume. The proportion of stem number per ha for hornbeam and ironwood was 21.2% and 26.9%, respectively.

While the volume proportion of these two species was 24.1% and 10.4%, respectively. Other species were counted to 11.5% of stem number and 9.7% of stand volume (Table 2).

Although the other species present in the stand reached a relatively high number (11.6%), they accounted for only 9.5 % of volume. Of total deadwood, standing deadwood accounted 32.6% and fallen deadwood consisted of 67.4 % within the canopy gaps. Total amount of deadwood was 27.75 $N.ha^{-1}$ and 45.4 $m3.ha^{-1}$, which was counted to 8.7% of total density and 9.1% of total volume of living trees. The fallen deadwood proportion of beech, hornbeam, ironwood and other species logs was 31.4, 32, 21 and 15.6%, respectively. The volume proportion of these three species was counted to 62.5, 25.51, 8.62 and 4%, respectively (Table 2).

Gap characteristics

Overall, 54 canopy gaps were identified on the permanent research plot with a total area of 7966.5 m^2 (Table3) that covers 4.98% of the total area. Minimum, maximum and mean gap size was 48.3, 622 and 147.5 m^2. Half of the gaps were smaller than 100 m^2, covering 2051.1 m^2, which counted for 25.7% of the total gap area. The other half of the gaps were larger than 150 m^2; among them only one gap was larger than 600 m^2 (Table 3). Gaps showed different directions, mostly north, south-west and north-west, counting for 33.3% north, 25.9% south-west and 16.7% north-west of the whole gaps. The highest mean gap size (ca. 140 m^2) was found on east and west directions (Table 4). Density of gap makers was 7.6$N.ha^{-1}$, and their mean, minimum and maximum DBH were 63.16 cm, 21.7 cm and 115 cm, respectively. Of total deadwood, standing deadwood counted to 32.6% and fallen deadwood consisted of 67.4% within the canopy gaps. Range of gaps varied within gap size, where 27 (50%) were in the gap class 100 m² and other species 50% were in the other gap classes. Only one gap (1.85 %) of total gaps recorded in the gap class was greater than 600 m². The largest gap area belonged to gap classes lower than 100 m² with 2051 m² and the smallest included gap class above 600 m² with (622 m²). The most frequent were the canopy gaps with the size from 48.5 to 150 m²; i.e., gap classes < 100 m² and 150 m² (68.5%). Whereas, more than 70% of these categories consisted of <100 m² gaps. About seventy-eight percent of the gaps was less than 200 m² in area and only 7% of the gaps exceeded 500 m² (Table 3) gaps larger than 300 m² composing 14.7 % of total gaps frequency, but they formed 35.1% of the total area covered by gaps. The mean frequency direction of tree falls and gaps were in accordance with the prevailing winds; e.g., North (0°) and southwest (240°) (overall 58% of total gaps) in the surveyed area (Table 4). Fig. 2 shows the distribution of the total gap area according to the size categories of canopy gaps. While the small gaps (<100 m²) made up nearly 50 % of gap maker, their proportion of the total gap area reached only 25.7%.

On the other hand, one largest recorded gap made up to 7.8% of the overall gap area. The most frequency of the gaps size <100-400 m² comprised about two-thirds of gap area, whereas the largest gap made up an over proportion amount of 9.6%.

Table2. Main characteristics of the living trees and deadwood on the studied permanent research plot.

Tree species	Density.ha^{-1}		Volume.ha^{-1}	
	N	%	m³	%
Living trees (DBH ≥ 7.5)				
Beech	115	40	263.4	55.80
Hornbeam	61	21.2	113.8	24.1
Persian ironwood	77	26.9	49.0	10.4
Other species*	33	11.5	45.80	9.70
Total	287	100	472	100
Standing deadwood (snags)				
Beech	2.6	24.8	5.1	56.7
Hornbeam	2.8	26.7	1.4	15.6
Persian ironwood	2.6	24.8	1.3	14.4
Other species	2.5	23.7	1.2	13.3
Total	10.5	100	9.0	100
Fallen deadwood (logs)				
Beech	5.4	31.4	22.7	62.5
Hornbeam	5.5	32	9.1	25.1
ironwood	3.6	21	3.1	8.62
Other species	2.7	15.6	1.47	4
Total	17.2	100	36.4	100

*Other species: date plum, alder, velvet maple and elm

Table 3. Characteristics of the studied gaps in the permanent research plot.

gap classes (m²)	number	%	Total area (m²)	%
<100	27	50	2051.1	25.74
150	10	18.5	1320.4	16.6
200	5	9.25	869	10.9
250	4	7.4	910	11.4
300	3	5.5	773.8	9.6
350	2	3.7	649.4	8.1
400	2	3.7	770.5	9.6
>600	1	1.8	622.4	7.8
Total	54	100	7966.50	100

Gap maker characteristics

A total of 95 gap makers were identified within the 54 studied gaps, making an average of 7.6N.ha^{-1}. More than third-quarter of the gaps were made by one or two gap makers, 50% by one, and 31.5% by two gap maker. There was only one gap that was made by 7 gap makers (Fig. 2). The area of gaps made by one gap maker varied between 48 m^2 and 252 m^2, while those made by 7 gap makers were 623 m^2 (Table 5). Beech was the most common gap maker (52%) followed by hornbeam (26.7%), ironwood (16%). Velvet maple, Caucasian alder and date plum were other gap makers with total proportion of 5.3 %.

The minimum, maximum and mean DBH of the gap makers was 21.7, 63.2 and 115 cm, respectively. The mean DBH of beech was the highest (70.6 cm) among the gap makers, whereas that of date plum (21 cm) was the lowest (Table 6). The most common cause of canopy gaps was a single tree-fall and two tree-fall events with (52 and 34%); while gaps caused by three and more trees were very little (14%).

The maximum number of fallen trees within a single gap opening was 7. Fig. 3 showed that beech had the highest percent of gap maker among species (52%) and Caucasian maple had the lowest (2.4%). Velvet maple had the highest frequency gap-filler among species (29%). As the tress creating gaps were identified using woody debris analysis, a two-tree gap might be identified in which the first tree died 40 years ago and the second tree one year ago. Regarding the land area of gap size classes, a distinctive disproportion between the gap frequency and gap area was observed.

Table 4. Characteristics of gaps in relationship with geographical direction.

Geographical gap direction	No of gap	%	Mean gap size (m^2)	%
N	18	33.3	131	14.2
NW	9	16.7	120.5	13.10
W	5	9.2	140	15.2
SW	14	25.9	119	12.9
S	4	7.40	97	10.5
SE	1	1.8	94	10.2
E	2	3.7	143	15.5
NE	1	1.8	75	8.1
Total	54	100	147.5	100

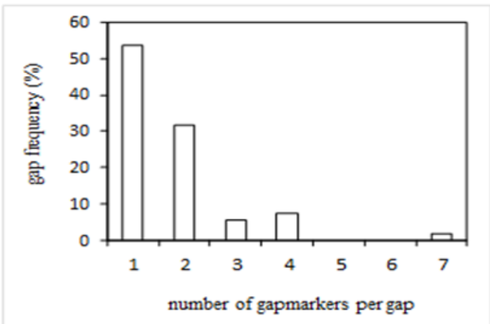

Fig. 2. Proportion of gaps made by gap makers.

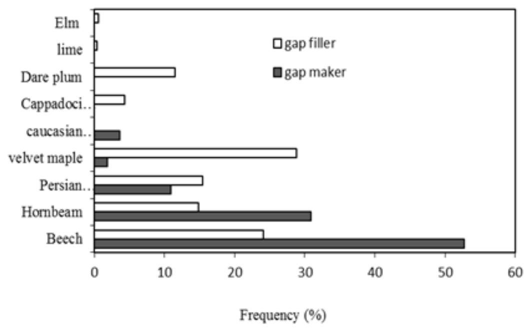

Fig. 3. Frequency of gap makers and gap filler species in the 54 gap studied.

Table 5. Characteristics of the studied gaps in relation to number of gap makers.

number of gap maker	number of gaps	Canopy gap size (m²)*	Total area (m²)
1	29	91.5 (48 - 252)	2655.5
2	17	166 (74.5 - 393)	2818.9
3	3	193 (154 - 234)	574
4	4	324 (269 - 378)	1296
5	0	0	0
6	0	0	0
7	1	623	623
Total	54	201.5	7966.5

* Numbers within parenthesis are minimum and maximum gap size.

Table 6. Characteristics of the studied gaps based on gap maker species.

Species	number of gap	%	Mean DBH (cm)	mean area of gap (m²)
Beech	39	52	70.6	160.5
Hornbeam	20	26.7	66	170.2
Ironwood	12	16	45.3	103.8
Velvet maple	2	2. 7	45.7	327.6
Caucasian alder	1	1.3	57.5	223.5
Date plum	1	1.3	21.0	236

Gap regeneration

A total of 37167.4 seedling and sapling per hectare were measured in the 54 gaps studied (Table 7). Velvet maple (28.8%) and beech (24.1%) had the maximum frequency among regeneration. Ironwood (15.4%), hornbeam (14.8%) and date plum (11.5%) were the next important contributors to the regeneration pool. Approximately, 84% of the total regeneration was shorter than 1.30 m in height class (Table 7). The proportion of saplings with DBH less than 2.5 cm was 11%, saplings with DBH 2.5-7.5 cm were 4% and regeneration with DBH 7.5-12.5 cm was 1%. The frequency of regeneration of different species in different gap sizes is given in Fig. 4. By increasing gap size, the number of beech regeneration decreases, while that of hornbeam and velvet maple increases.

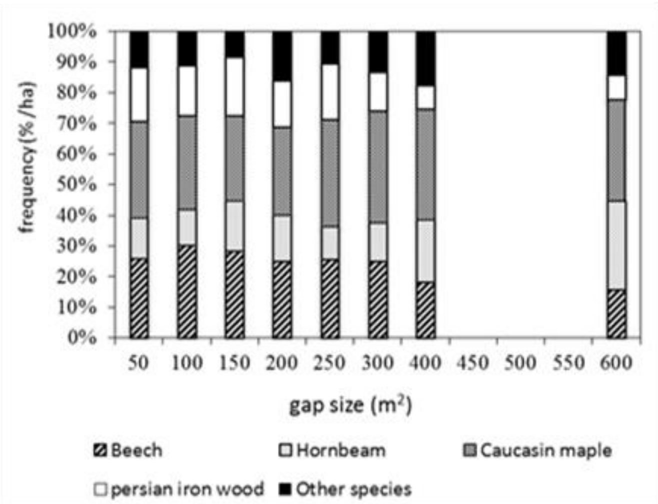

Fig. 4. Proportion of regeneration of different species in different gap sizes.

Table 7. Number and frequency of seedlings and saplings (N.ha^{-1}) by species in the canopy gaps on the permanent research plot.

	Height class (m)				Diameter classes (cm)					
Species	**≥1.30**	%	**≤2.5**	%	**2.5-7.5**	%	**7.5-12.5**	%	**Total**	%
Beech	7496.1	23.8	831.2	20.2	466.9	36.7	150.4	45.6	8944.7	24.1
Hornbeam	5058.8	16.1	348.7	8.4	105.7	8.3	20.7	6.3	5534	14.8
Ironwood	4268.1	13.5	1060.2	25.6	345.2	27.2	66.3	20.1	5739.8	15.4
Velvet maple	9821.4	31.2	809.3	19.6	75.2	5.9	9.5	2.9	10715	28.8
Date plume	3339.5	10.6	629	15.2	224	17.6	82.6	25	4275.2	11.5
Cappadocia maple	1450.8	4.6	113.7	2.7	52.8	4.2	0	0	1617.4	4.35
Lime	0	0	132.6	3.2	0	0	0	0	132.62	0.35
Elm	0	0	208.2	5	0	0	0	0	208.15	0.56
Total	31414.8	100	4133	100	1269.9	100	329.9	100	37167.4	100
%	84		11		4		1		100	

DISCUSSION

Ecosystems are a product of the interactions of biota, climate, edaphic conditions, and disturbance processes. Over long periods, species best suited to the prevailing conditions eventually succeed and dominate (Denslow, 1980). This study in the Shastkalateh Forest, Hyrcanian region revealed the characteristics of canopy gaps in a natural unlogged oriental beech forest. The results of this study showed that density and volume were 287 N.ha^{-1} and 472 m3.ha^{-1}, respectively. Beech had the highest proportion volume of living trees (55.8%) and deadwood (62%) among other species (Table 2). It can be concluded that the structure of studied natural unlogged oriental beech forests in the Hyrcanian region is old growth, irregular and uneven-aged. Previous investigations in Hyrcanian Forests confirm this findings, too (Fallah, 2000; Sagheb-Talebi & Schütz, 2002; Sagheb-Talebi *et al.*, 2005; Habashi *et al.*, 2007). Results showed that canopy gap size varied between 48.5 m^2 and 623 m^2. Total canopy gaps area was 7966 m^2 which nearly covered 5% of the permanent research plot. Sefidi *et al.* (2011) found that canopy gaps covered 9.3% of the total forested area in the mature *Fagus orientalis*-dominated stands of Northern Iran. This amount is less than the value obtained in the study of Sefidi *et al.* (2011), but close to the 4% of total forest area in the unmanaged stand in natural beech forest in the Keyrodkenar, Noushar (Mataji *et al.*, 2008) and 4.7% identified for mature *Picea-Fagus* forests in the Appalachian Mountains of the Eastern United States (Rentch *et al.*, 2010). Although, canopy gap fraction generally decreases with stand age (Hart & Grissino-Mayer, 2009), management can also influence gap fraction (Sefidi *et al.*, 2011). Also, Zeibig *et al.* (2005), found a 5.6 % gap proportion and 137 m^2 average gap sizes in Krokar (Slovenia). The size of gaps is obviously closely linked to the number of trees involved in its creation. We found that most gaps were formed from single and then two tree-fall events and identified no gaps formed by 5 and 6 gap makers. But we found only one gap formed by 7 gap makers. In contrast, Sagheb-Talebi *et al.* (2005) in the Mazandaran forests of Northern Iran, found gaps that were formed from up to six treefall events while Delfan-Abazari *et al.* (2004), in the Kelardasht forests, of Northern Iran, found most gaps were created during double - tree fall events. Sefidi *et al.* (2011), who worked at the Kheyrudkenar Experimental Forest, found one characteristic of canopy gaps that differed from the others. They determined that the most canopy gaps are formed by one tree-fall and there was not any gap that formed by more than 4 gap makers. Although our site represents a mature beech forest, the trees are growing on well-drained, deep soils which may reduce the likelihood of a single tree-fall event cascading into multiple trees.

The results of this study showed that 86% of the gaps area fluctuated between of 50 and 200 m^2 which is consistent with Delfan-Abazari *et al.* (2004) in the Kelardasht forest found that the area of most of the gaps varied from 300 to 500 m^2, but the results of study conducted by Sefidi *et al.* (2011) were similar to these of the present

study. Also other studies suggest different gap area ranges from 80 to 1230 m^2 in the Golband forest, 89 to 2279 m^2 in the Asalem forest (Amanzadeh *et al*. 2004), 63 to 1383 m^2 in the Mazandaran beech forest (Sagheb-Talebi *et al*., 2005) and 34 to 579 m^2 in the Kheyroudkenar, Noushar (Mataji *et al*., 2008). Researches in Iranian beech forests identified that most gaps are formed as a result of single tree-fall (Sefidi *et al*., 2011) and two tree-fall event (Delfan-Abazari *et al.,* 2004; Sagheb-Talebi *et al.,* 2005).
Nevertheless, we found that substantial majority of gaps were formed by single tree-fall event. Usually, beech has higher frequency than other species in the small gaps (Shabani *et al.,* 2011). Research in forests in Slovenia showed that Acer requires large gaps to successfully reach the overstory, but Fagus sylvatica was able to reach the canopy in all gap sizes and was particularly successful in capturing gaps that were < 400 m^2 (Najel *et al.,* 2010). The same patterns may exist in the Iranian forests and would explain the presence of beech and Velvet maple seedlings in all gaps, but the dominance of beech as gapmaker. The growing conditions for the young seedlings and sapling within a gap are also dependent upon gap size. Seedlings and saplings growing in the smaller gaps found in beech forests will experience lower cover from competing herbaceous cover and faster litter decomposition rates (Galhidy *et al.,* 2006). The results of this study showed that the frequency regeneration of beech and ironwood regeneration decreased with increasing gaps size. In contrast, frequency Velvet maple, hornbeam and other species (including date plum and Cappadocia maple) enhanced. One reason is that the beech is a shade tolerant species and with expanded gap area the environmental conditions for its regeneration decreases. Because, more light reaches the surface of canopy gap.
Maple, date plum and even hornbeam are light demanding species that have more frequency than shade tolerant species within large gaps. While studying forest dynamics, in - depth knowledge on regeneration has both theoretical and practical importance. Our findings in this study indicated that an average of regeneration for a total of the species was 37147 $N.ha^{-1}$. Velvet maple and beech had more than half of regeneration amount in the canopy gaps allocated. Other studies in the Hyrcanian Forests reported the number of seedlings and saplings of all species between 10300 and 17600 (Delfan-Abazari *et al.,* 2004) and 30 thousand to 120 thousand $N.ha^{-1}$ (Amanzadeh *et al.,* 2004). The amount of regeneration in our study in Golestan Province was higher than in Kelardasht Forest in Mazandaran Province (Delfan-Abazari *et al.*. 2004) and Kheyrud Forest with 3398 Nha^{-1} (Sefidi *et al.* 2011). Kenderes *et al.* (2008), found that average seedling density in the studied natural gap was between 40000 and 50000 per hectare which is regarded as sufficient for restocking managed beech stands by natural regeneration. Research in the Caspian Region demonstrated that, although oriental beech regeneration had the best growth characteristics within gaps larger than 1000 m^2, more well-formed and healthy saplings were found within gaps of 200–500 m^2 (Sagheb-Talebi & Shütz, 2002). Tabari *et al.* (2005) concluded that small gaps provide a higher stability and more favorable environmental conditions for survival and growth of beech seedlings. Also, lack of sufficient seedlings within the openings of the beech forests of Iran is due to regeneration deficiency, weed competition and seed production deficiency.
Therefore, where advanced regeneration of beech is present, all chances for further development should be given by gradually opening the canopy layer. Also, according to Hungarian forestry regulations, the presence of at least 10000 individuals per hectare is required for regeneration to be accepted as successful. Mihók *et al.* (2005) and Gálhidy *et al.* (2006) for Hungarian beech forests confirmed the effects of gap size on regeneration success. Korpel's (1995) studies showed that the regeneration in European virgin beech forests occurs in small groups with a surface area of 100 to 200 m^2, and openings of over 2000 m^2,

which could be covered by regeneration in the late decay stage, are a seldom.

Our study focuses on gap regeneration patterns in a natural unmanaged Oriental beech stand. Although we only showed a snapshot of a dynamic process, we tried to interpret the findings as an outcome of several important dynamic processes: gap existence, tree regeneration, gap maker characteristics, geographical direction gap and coexistence of other species. Our findings emphasize the importance of the spatial scale of disturbances, and of the gradual change in abiotic factors (e.g. light) from below canopy to gap center in gap-studies. Gap regeneration patterns depend not only on the ecological traits of tree species (e.g. light demanding, shade - tolerant etc.), but also among others, on the composition and cover of herbaceous vegetation and on game browsing. Therefore, gap studies should focus on these factors as well, in order to get a better understanding of regeneration mechanisms of forest stands. In situations where forest managers are attempting to increase the establishment of beech in managed stands through the creation of gap, Sefidi *et al.* (2011), indicate that there is no relationship between canopy gap size and density of beech seedlings. However, it is important to differentiate between seedling germination (characterized by the seedling density that we measured) and seedling establishment. Results of Kenderes *et al.* (2008), study also indicated that natural regeneration was possible in naturally occurring gaps. Both the density and species composition of regeneration would enable the development and long-term maintenance of mixed beech-dominated forests. In conclusion, we argue that in spite of the limitations set by their small size and the negative effects from the surroundings (e.g. longevity, diseases, and wind), forest reserves are useful tools of studying natural processes in the Hyrcanain forest.

Taking into account the stand structure and light regime in small and medium-sized gaps, the potential for the application of the group selection system in Caspian beech forests has recently been investigated (Sagheb-Talebi & Schütz, 2002), where the removal of two to four main trees is proposed. It should be noted that beech and Velvet maple were the most common gap filler even though the main gap makers were beech, hornbeam and Velvet maple. This suggests that a shift in species composition is occurring, though slowly. Schütz (2006) states that: "Because beech species is shade tolerant, single-tree selection would provide great flexibility in controlling residual stocking, tree quality, and establishing a cutting cycle that meets both ecological and economic objectives". More intensive measures, such as understory weed control and planting, may be needed for those forests lacking adequate beech regeneration. However, given the paucity of experimental evidence and potentially changing environmental conditions, we believe our study provides a foundation that forest managers could use to develop adaptive forest management techniques for restoration objectives. Canopy gaps are the dominant source for regeneration in mature beech forests in Northern Iran (Sefidi *et al.,* 2011). Most gaps form single-tree fall events and the deep soils in this region may prevent the cascading effect of surrounding trees following the initial tree fall. Thus, most gaps tend to be small (medium gap size was 178 m^2) and small gaps were irregular in shape. Across the range in gap sizes that we measured (19.6 – 2246 m^2) there was no relationship between gap size and seedling density for either of the dominant species in this stand (*F. orientalis* and *A. velutinum*). Oriental beech was clearly superior at capturing canopy gaps compared to other species and was identified as the definitive gap filler in 93% of the gaps. A weak point of the present study is the fact that no gap sizes between 200 and 600 m^2 were studied. Although we clearly found different seedling responses between small (50 and 200 m^2) and large gaps (600 m^2 and more), it was not possible to determine the "critical gap size" exactly, at least if there is one. Another weakness is the relatively short monitoring period. Similar researches can, therefore, be recommended over longer time periods in such gap sizes and also in gaps of 200–600 m² (with several replicates) of various beech stands, with different exposition, inclination and altitude. The findings of our study can be used for the development of techniques and treatments for close to nature silviculture in the beech stand forest. The observed gap dimensions and other characteristics of canopy gaps can guide forest managers and researchers towards practices that ensure continuous forest cover.

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پویایی ویژگی روشنه‌های تاج‌پوشش در یک جنگل طبیعی بهره‌برداری نشده راش شمال ایران

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چکیده

روشنه‌های تاج پوشش یکی از مهم‌ترین ویژگی‌های ساختاری اکوسیستم‌های جنگلی می‌باشند که مطالعه آنها نتایج و کارکردهای ارزشمندی برای مدیریت جنگل دارد. هدف از این مطالعه بررسی ویژگی‌های روشنه‌های تاج‌پوشش و تجدید حیات داخل آنها در یک توده طبیعی بهره‌برداری نشده راش در جنگل شصت‌کلاته گرگان می‌باشد. برای این منظور همه روشنه‌های تاج پوشش و مشخصه‌های مرتبط با روشنه‌ها در داخل یک قطعه نمونه دائمی به مساحت ۱۶ هکتار اندازه‌گیری شد. سپس در هر روشنه دو پارامتر طول و عرض روشنه جهت محاسبه مساحت روشنه برداشت گردید. با توجه به ترکیب جنگل، راش با ۳۶/۳٪ تعداد و ۵۶/۶٪ حجم در هکتار گونه غالب توده بود. در مجموع ۵۴ روشنه تاج پوشش شناسایی و ثبت شد که حدود ۵٪ از سطح کل قطعه نمونه ۱۶ هکتاری را پوشش می‌دادند. میانگین تراکم روشنه‌ها ۴/۳۲ روشنه در هکتار بود، که مساحت آنها بین ۴۸/۳ تا ۶۲۲/۷ مترمربع نوسان داشت. بیش از سه - چهارم (۷۷/۷٪) از روشنه‌ها مساحت کمتر از ۲۰۰ مترمربع داشتند. همچنین، بیش از نیمی از روشنه‌ها (۵۳٪) توسط افتادن یک درخت بوجود آمده بودند که گونه راش ۵۲٪ درختان روشنه‌ساز و ۲۳/۴٪ از درختان پرکننده روشنه را تشکیل می‌داد. راش بیشترین سهم خشکه‌دار سرپا را در بین درختان روشنه‌ساز داشت، در حالیکه پلت بیشترین فراوانی درختان پرکننده روشنه به میزان ۳۰٪ را شامل می‌شد. به رغم فراوانی بالای روشنه‌های کوچک با مساحت کمتر از ۱۰۰ مترمربع، سهم آنها در مجموع ۲۵٪ مساحت کل روشنه‌ها بود. این موضوع اهمیت نقش روشنه‌های متوسط و بزرگ را پویایی روشنه نشان می‌دهد. با توجه به آشفتگی‌های بوجود آمده اخیر در جنگلهای خزری (خشک‌سالی، آتش‌سوزی، تغییرات اقلیمی)، مطالعه حاضر ویژگی‌های مهم رژیم‌های آشفتگی را با تاکید بر نقش باد و دیرزیستی درختان تعیین کرد. در مجموع، یافته‌های تحقیق حاضر نشان داد که ایجاد روشنه‌های کوچک و متوسط در جنگلهای طبیعی دست نخورده راش می‌تواند بر اساس رژیم‌های آشفتگی طبیعی باشد که این روشنه‌ها شرایط مناسبی را برای تجدید حیات موفق جنگلهای راش با توجه به فلسفه جنگل‌شناسی نزدیک به طبیعت فراهم می‌کنند.

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