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Effect of a Windstorm on Gaps Structural Characteristics in the Different Forest Stands in Darabkola Region, Mazandaran Province

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ABSTRACT

Aims: Natural disasters have been extensively identified as significant events shaping vegetation structure. In recent years, natural and unforeseen disturbances in forest ecosystems have increased. This research aims to survey the gap characteristics of the outbreaks created by the autumn 2015 windstorm in the Darabkola forest in Sari, Hyrcanian region.

Material & Methods: Six sample stands of broad-leaved species based on dominant tree species (%) —1= Oriental beech (44.6%), 2= Common hornbeam (38%), 3= Common hornbeam (40%), 4= Oriental beech (45.5%), 5= Ironwood (50.6%), 6= Caucasian alder (60.8%) —were selected. In each sample stand to measure gaps characteristics, randomly deployed 4-10 transects in the north–south direction, differing in length from 130 to 350 m all over the area using the line intersect method. Also, they were separated by 80 m from each other. We premeditated a ratio of length to width and diameter to height ratios for created gaps. Also, gap size, average canopy height, and gap area were analyzed for relevance between gap-creation mechanisms. Each species ' relative frequency, density, dominance, and importance were calculated considering measured trees inside gaps and per whole area. The Fisher test was used to compare the gap number and the severity of damage. All statistical tests were executed using SPSS ver. 20.

Findings: Our finding showed that variability in the gap size created by windstorms was very high, stretching from 20.2 to 4600 m^2 in the sample stands. The number of gaps with an area >1000 m^2 was the most. In oriental beech stands, where the biggest median gap area was detected (~318 m^2), the total area of gaps was also the highest (80760 m^2). The density of shade tolerance or less light-demanding species in the gaps (335 and 428 individuals for beech species) was more significant than light-demanding ones. Beech and Hornbeam gap makers were in all gap sizes, and all sample stands, and their density increased with gap extent, especially in the gaps with beech dominant. The variables based on gap physical characteristics (size, shape, direction, elongation) were less significant than variables from other classes. Dispensation agreed with the lognormal distribution accompanying the parameters U = 8.43 and r= 0.37 (σ^2 = 1.67, df =22, P = 0.043) between the sample stands.

Conclusion: According to the results, the number and area of gaps created by the windstorm can vary according to stand structural characteristics such as species, stand composition, developmental stages, layers story, tree height, the root system, tree crown tendency, and crown area, and the physiographic and soil conditions. It was determined that the gap sizes in the sample stand with more species (the sixth stand with 11 species) are more significant than those with fewer species (the fifth stand with six species). At the same time, the gap number was higher in the stands with fewer species diversity (the third and fourth stands have 213 and 151 gaps, respectively). Plenty of windstorm damage occurred in upper-slope situations and locations where old-growth forest stands with large crowns and shallow root systems.

Keywords: Stand structure; Natural disturbance; Mixed forest.

CITATION LINKS

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Introduction

Windstorm is one of the important meteorological (abiotic factors) extremes, together with biotic factors, influence human societies [1] and also an essential natural perturbation in many natural ecosystems throughout the world, especially in temperate forests [2,3,4,5,6,7,8]. The occurrence of windstorms may cause human losses, few of the ruling class is perilous, with patterns written down daily for both historical and more current windstorms, as well as causing severe damage to individual trees growing in gardens, parks, roadsides, and streets or forest stands [9,10,11]. Detriment due to windstorms has risen since the mid-20th century concerning changes in forest management activities and likely climatic changes [12,7]. This current is expected to carry on, reducing the carbon storage potential of forests [13] and causing intensive loss in their conservation, economic, and ecological values [14]. Disasters by windstorms vary spatially and temporally in forests. They operate mainly from tiny-scale incidents at the level of individual trees and stand structures to prominent destructive disturbances operating at the landscape level [15,16,17,18,19,8]. However, windstorms can also change soil structure, commence ground layer successions, and impact tree regeneration in different phases [20,21,22,23]. Also, Large windstorms, affecting entire communities, are infrequent [24], while small-scale windstorms are prevalent and play a central role in gap dynamics [25,26].

The direct impacts of exceeding windstorms on forest stands are mirrored in windstorms that take different forms: Disconnection of the crowns in part or entirely, trunk breaking, uprooting, or bending of the entire tree [27,28,29]. Many studies have been assigned to different aspects of windstorm turbulences in forests. Prior researchers like; Lugo [30], Kooch et al. [31], Sefidi et al. [23], Mitchell [32], Seidl, et al. [13], Amiri et al. [19], Orman et al. [33], Ahmadi [34], Zenner et al. [35], Khodaverdi et al. [26], Torun and Altunel [36], and Mataji and Vahedi [37] had reviewed the impact of windstorm on forest structure and the creation gaps of small (~10 m^2) to large scale (~5000 m^2) in different forest stands. On the other hand, creating natural and artificial gaps has long been an impressive silviculture measure to preserve continuous forest cover and stand structure [38]. Gaps warrant the successful preservation of tree regeneration and the constancy of the stand structure [39,40,41]. Forest gaps, which mainly result from selection cutting or intensive winds, snow compression, or pests and diseases in a dense forest, can enhance the discontinuity of resources and environments and contribute to the symbiosis and growth of species accompanying various life history procedures [42,43].

In Iran, Hyrcanian forests, including unique massif and old-growth mixed stands, stretch 850 km in a west-to-east direction of the Caspian Sea [44,45]. These forests have a remarkable biodiversity, which includes a high plant species richness of >80 woody species [45], and since 2019, they have been considered UNESCO World Heritage sites [46,47]. In recent years, due to climate changes, silviculture operations, and improper utilization, windstorms have been one of the most important causes of disorderliness in the Hyrcanian deciduous forests [48]. Thus, we conducted an extensive study in one district of Darabkola Forest., covering the whole area set aside for investigation aims after the windstorm in October 2015. Our primitive objective was to compare the characteristics of gaps created by windstorms in a mixed forest north of Iran. For this purpose, 6 sample stands with different species compositions were considered.

Material & Methods

Study Area

The research was done in one district of Da-

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rabkola Forest, having an area of 2612 ha, Sari, Mazandaran Province, north of Iran (36° 23′ to 36° 33′ north latitude and 52° 20′ to 52° 31′ east longitudes) on the lower altitudes of the northern edge. Average, minimum, and maximum annual temperatures are 16°C, 7.5°C (in December) and 21.1°C (in June), respectively. The mean annual precipitation is 984 mm, with a growing season lasting 200–250 days [49]. Based on USDA, the soil taxonomic classification is Alfisols and Inceptisols. Also, soil texture is clay-loam to loam regarding soil profile [49, 50]. Elevations vary from 160 to 160 and 710 m above sea level. The mean slope in most parts was 30%, and the general aspect was northern (Figure 1). One district, Darabkola Forest, the aim of our study, is dominated by mixed broad-leaved species of *Fagus orientalis* L (Oriental beech), *Carpinus betulus* L. (Common hornbeam), *Acer velutinum* Boiss., *Acer cappadocicum* (velvet and Cappadocian maple), *Alnus subcordata* (Caucasian alder), *Parrotia persica* (Ironwood), *Diospyrus lotus* (date plum), *Ulmus glabra* Huds. (Elm), and minor components of other species (*Acer cappadocicum* Gled, *Tilia begoniifolia* Steven, *Juglans regia*, L. and *Salix nigra* Marshall). The studied forest

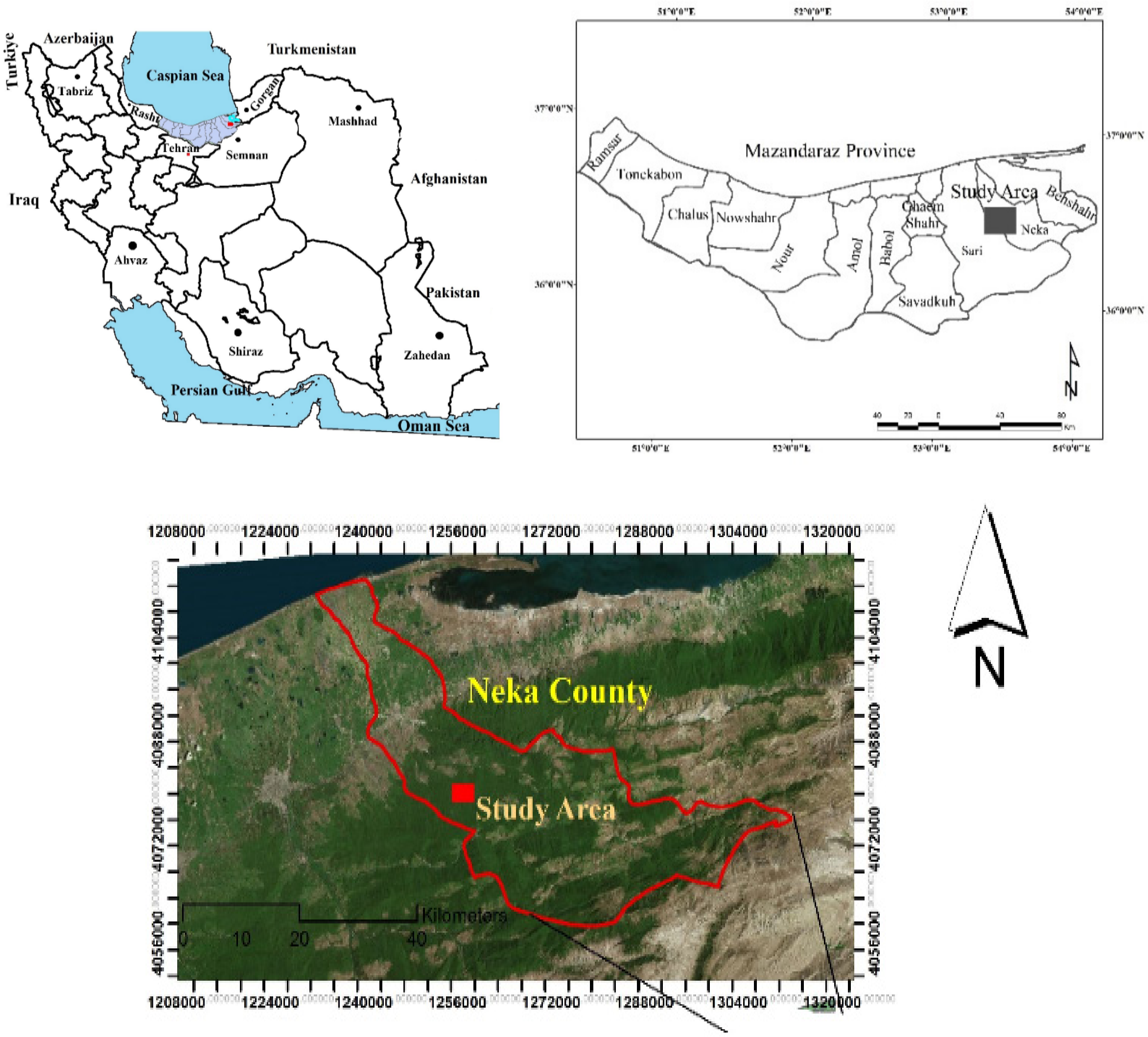

Figure 1) The study region: Darabakola Forest, Mazandaran Province, and its location within Hyrcanain Forests, North of Iran.

stands are often two to three stories high and have a top height of 30 m [49]. A windstorm influenced the south and southeastern part of Sari in mid-October 2014; it is probably the largest reported wind disturbance (both by scale spatial affected and damage of trees) in the Hyrcanian region, Mazandaran Province. A windstorm blasted from the north, and the maximum sustained wind speed attained 110 km. h [34]. The whole area of windstorm-damaged stands was equal to 653 ha (about 25% 2612 ha), and the total amount of salvage-logged timber was approximately 8541 individuals and 20 thousand m^3, respectively [34]. The weather forecast reports demonstrated that no significant windstorms had affected northern Iran. Similarly, historical data shows that although numerous temperate windstorms regularly pass over northern Iran and Hyrcanian forests, most windstorms have not made landfall in this region [51].

Field Investigation and Sampling Method

To investigate the characteristics of gaps created by windstorm, six sample stands of broad-leaved species based on dominant tree species (%) —1= Oriental beech (44.6%), 2= Common hornbeam (38%), 3= Common hornbeam (40%), 4= Oriental beech (45.5%), 5= Ironwood (50.6%), 6= Caucasian alder (60.8%) —were selected (Table 1). Sample stands were located in areas where they were reasonably homogenous for slope and aspect. Gaps created by windstorms (total: 630 gaps) were located along transects throughout the area using the line intersect method [52,53,54]. We established north-south transects differing in length from 130 to 350 m, and the numbers of transects ranged from 4 to 10 depending on the extent of the homogeneous stands' structure. In addition, transects were established from a randomly selected point and paralleled the slope contour of the topography within each sampled stand. Transects were separated by 80 m in the sample stand (Figure 2). We aimed to envelop the entire area of strictly damaged stands by transects.

For the six stands studied, we recorded gaps

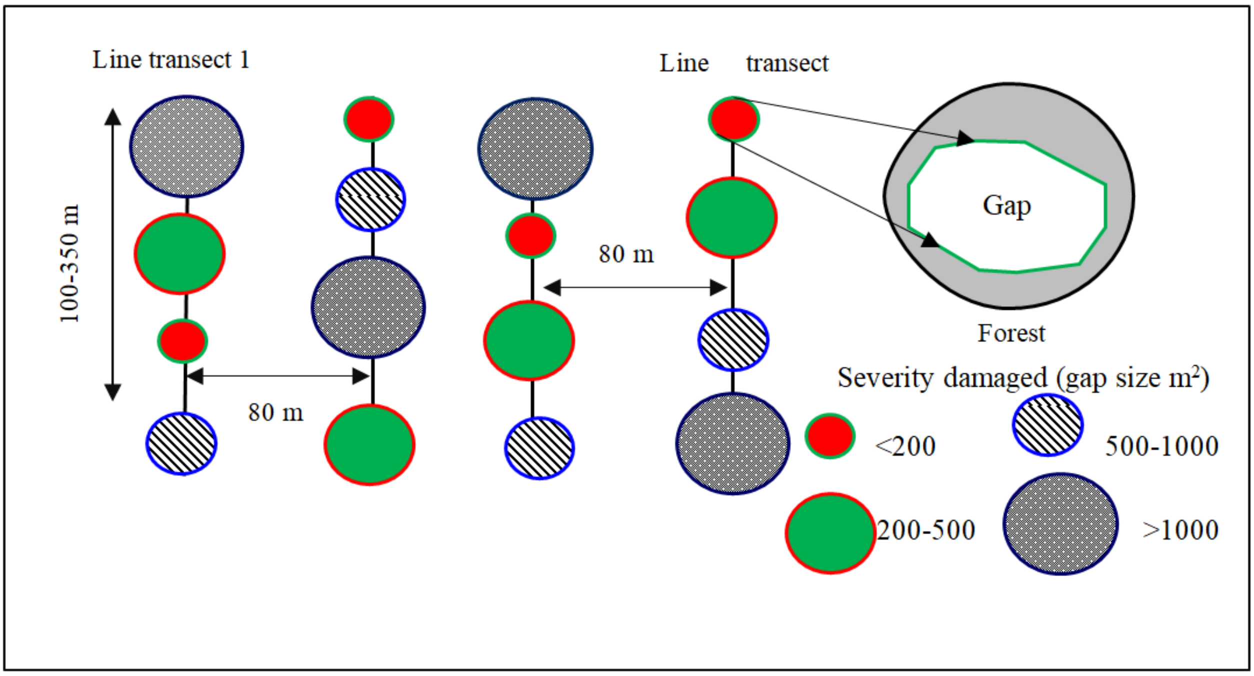

Figure 2) Schematic illustration of the study design applied at the six sample stands. The distance between transects was at least 80 m.

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Table 1) Dominant trees, composition species, density, and volume for stem ≥12.5 cm D.B.H. before the windstorm in the studied forest stands.

Stand	Study survey (ha)	Altitude (m asl)	Slope (mean %)	Dominant tree species	Composition species (%)	Density (n.ha)	Volume (m^3.ha)
1	91	700-790	35	Oriental beech	**beech (44.6)**, hornbeam (13.5), Caucasian alder (33), ironwood (2.4), maple (4.5), other species (2)	173	310
2	76	650-760	43	Common hornbeam	beech (19), **hornbeam (38)**, Caucasian alder (23.7), ironwood (9.4), maple (5.3), oak (0.7), capadocicum maple (0.9), other species (3)	206	303
3	72	710-775	40	Common hornbeam	beech (21), **hornbeam (40)**, Caucasian alder (12.3), ironwood (10.4), maple (8.5), date plume (2.6), capadocicum maple (2.5), other species (2.7)	195	292
4	86	620-720	30	Oriental beech	**beech (45.5)**, hornbeam (17.5), Caucasian alder (16.2), ironwood (8.6), maple (5), date plume (2.5), capadocicum maple (1), other species (3.7)	155	346
5	44	620-730	22	Ironwood	beech (13.7), hornbeam (20.4), Caucasian alder (5.5), **ironwood (50.6)**, maple (3.2), date plume (2.8), other species (3.8)	146	206
6	36	630-660	15	Caucasian alder	beech (24.5), hornbeam (4), **Caucasian alder (60.8)**, ironwood (2.6), maple (6), date plume (2.6), capadocicum maple (1), other species (1.1)	215	262

created by windstorms. A gap can be formed [1]by the mortality of one or more trees from the upper tree layer, defined as an opening in the canopy with at least 20 m^2 [19,26]. In this study, only gaps that were created by windstorms were considered. For each gap, two attributes were measured the length (L) as the most extended interval and the width (W) as the most significant distance perpendicular to the length. The gap form was considered as the ellipse. The area of the gap was calculated using the formula for an ellipse: Eq. (1) $A=\pi LW/4$ [52,55,23], where A is the gap area in m^2, L is the longest interval in the gap, and W is the most significant distance perpendicular to the length in meter. In each gap, the species, D.B.H. of all trees ≥20 cm to characterize forest gap vegetation and the number of gap makers (only trees damaged of D.B.H.≥20 cm were considered) were recorded, and the mode of mortality (i.e., snag, uprooted or snapped) were identified [56,57,19,26].

Also, gap sizes were classed based on the severity of damage into small gaps (<200 m^2), medium gaps (200–500 m^2), large gaps (500-1000 m^2), and very large gaps (>1000 m^2) [37,23,26]. The gap sizes varied (from 0.002 to 0.45 ha) but were sufficiently large to represent the forest stand structure. Estimates were made of each gap coverage area by transects and the total area of gaps for each sampled stand. Also, other physical habitat features containing elevation, latitude, and longitude (using a G.P.S. receiver), slope (%), aspect, and average canopy height surrounding the gap were

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recorded in the field. Canopy height was measured using a Laser Distance meter (Leica Disto D5, Haglöf, Sweden).

Data Analysis

For created gaps, we computed a ratio of length to width (L: W) [58, 59, 23] and diameter-to-height ratios (D: H) using gap width (W) as diameter and average canopy height gaps [60, 61]. Two-tailed t-tests were used for the relationships between gap creation and projected gap closure mechanisms. Pearson correlation analysis and linear regression were used to analyze relationships between gap sizes with gapmaker D.B.H. Characteristics such as gap size, average canopy height, and gap area were analyzed by ANOVA with Scheffe post hoc tests within gaps and between sample stands. Relative frequency (percent of gaps in which each species occurred), density (contribution of each species), dominance, and relative importance of each species were calculated considering measured trees within gaps and per whole of gap area. One-way ANOVA tested differences in gap numbers in severity damaged categories. Duncan Multiple range tests were used to compare the severity of damage (based on gap size) in the studied stands. All analyses were performed using the SPSS $_{\text{version. 20}}$ (I.B.M. Corporation) after being visually assessed for normality.

Findings

A total of 630 gaps were observed in the sample studied stands, of which third and sixth stands, with 33.8% and 3.8 %, had the most and the least frequency, respectively. The total of 213 gaps, at a mean density of 4 gap ha^{-1}, within the third stand produced maximum gap per ha, versus 24 gaps, averaging 1.6 gap ha^{-1}, in the sixth stand produced minimum gap per ha. The mean gap size was maximum in six stands (695 m^2) and minimum in two stands (283 m^2). Also, the third stand, with about 8.76 ha, devotes the most area among all sample stands (Table 3). The average gap size differed significantly between the sample stands (F=456, *P*=0.01), with average gap areas of 427 (Standard deviation (SD) 183) m^2 (range: 20–4150 m^2) that covered 18.9 percent of the total area of the studied area (Table 3).

Table 4 shows the distribution of the gaps in the studied stands based on the severity of the windstorm damage (gap size). At all levels of damage, there is a meaningful difference between the number of gaps created in the sample stands (Sig. 0.015, df=4; F=66.81). At a gap size of less than 200 m^2, the maximum gaps belong to the third stand and the minimum to the sixth. The significant difference in the level of damage in the gaps less than 200 m^2 is 0.003 (F=73.93). There was a significant difference between the studied stands in the method with a gap size greater than 1000 m^2 (Sig. 0.005; F=21.75). In addition, the fourth stand with 30 gaps (52.6 % of total gaps in the very large category) has the most gaps larger than 1000 m^2 (Table 4).

The analysis confirmed that the gap size distribution is consistent with the lognormal distribution with the parameters U = 8.43 and r= = 0.37 (σ^2 = 1.67, df =22, P = 0.043) between the sample stands (Figure 3). In the sixth stand, one gap is larger than 4000 m^2. The most frequent were the gaps with a size of up to 200 m^2 (56.4%) belonging to the first stand, whereas more than two-thirds of this class were composed of gaps ≤100 m^2. The frequency distribution of gap size in the sixth stand did not differ remarkably from the lognormal distribution accompanying the parameters U = 5.64 and r = 0.62 (σ^2= 7.55, df = 11, P = 0.753). Gaps are diverse from 52 to 800 m^2, except for two large gaps of 3575 and 4150 m^2, respectively (Figure 3).

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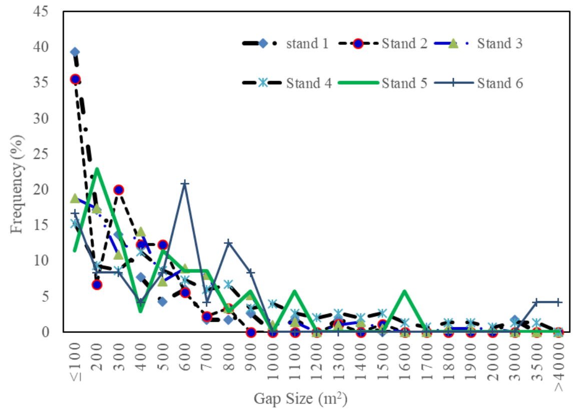

Figure 3) Mean sizes (±SD) of created gaps by windstorm phenomenon in Darabkola forest, Sari, Iran. Different letters showed a significant (P < 0.05) difference between gaps, as detected by the ANOVA test.

Characteristics of Gapmakers

The relevance between the diameter of gapmaker trees and gap size in sample stands detected that there is a significant difference between the two variables. In the second and third stands (the dominant species is hornbeam) and fourth (the dominant species is beech), gap size increased with the increased diameter of the gapmaker. In contrast, in one, fifth, and sixth stands, gap size decreases with the increases of the diameter gapmaker (Figure 4).

305, 270, 597, 606, 85, and 246 gapmaker trees that created the 117, 90, 213, 151, 35, and 26 gaps were recorded in the one to the sixth sample stands, respectively. The most frequent gapmaker trees were oriental beech (more than 70.3 percent), followed by common hornbeam, Caucasian alder, and velvet maple. The number of species woody preoccupied in the creation of a gap ranged from 1–6 in the fifth stand and 1–10 in the sixth stand (Table 5), with no significant difference in the frequency distribution of the number of gapmakers per gap between all of the sample stands (Figure 5). The mode of gapmakers in each sampled stand was one tree, the most of the gaps were created by 1–2 gapmakers (the range varied from 20.8 percent in the sixth stand to 70.1 percent in the one stand) and >20 percent of gaps were created by 3–4 gapmakers in all sample stand. The relative frequency of gaps created by 5–10 gapmakers was lowest in the one stand (9.4 percent) compared with the sixth (~38 %). Although the average DBH of gapmakers varied significantly (U=16320, *P*<0.06) between the one sample stand (mean: 81.4 (1.6) cm, range: 20–150cm), and second stand (mean: 73.8 cm, range: 20–135 cm) third stand (mean: 77.7 cm, range: 20–140 cm); fourth stand (mean: 71.5 cm, range: 20–120 cm), fifth stand (mean: 63.8 cm, range: 20–115 cm) and sixth stand (mean: 64.2 cm, range: 20–120 cm) (Figure 4).

Discussion

The present study showed the characteristics of the gaps created by the windstorm of 2015 in six sample stands with different compositions and structures in the Hyrcanian region, North of Iran. Damage to forest trees by natural factors such as storms, winds, and snow is part of ecological processes in a natural ecosystem that can lead to natural selection in plant populations and communities [62]. Regarding the whole area, fraction contributed to each gap size class; it was illustrated that the entire gap extent in the study stands at 24.14 ha (~6% of 405 ha). Falling of trees as a result of natural disturbances such as the creating natural gaps in mixed beech broadleaf stands of the Hyrcanian region, up to 30% of the standing stock is normal [19,26], which is a portion of the consequence of natural occurrences of storms, wind, and snow, On the other hand, economic damages of windstorm in managed forests can be perused. Especially in recent years, climate change has increased wrecking events such as storms, wind, and snow [63]. Indeed, forest disturbances, such as gaps created by natural events, vary between different types

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of forest stands. More than 90% of the gaps created by windstorms were assigned to oriental beech (42.5%; sum of the first and fourth stands) and hornbeam (48%; sum of second and third stands) sample stands (Table 3). Table 1 also partially confirmed these results. The stand composition before the windstorm showed that oriental beech, hornbeam, and Caucasian alder constituted more than 73% (except the fifth stand, which was less than 40%) of the stand frequency. The gaps varied in size from a minimum of 20 m^2 to a maximum of 4150 m^2, and the first stand with 20 m^2 and the sixth stand with 4150 m^2, respectively, had the smallest and largest gap among the studied sample stands (Table 3). Investigations in the Hyrcanian region showed that the gap size was very floating, so in the study Mataji and Vahedi [37] in Glandrood district from 68 to 1538 m^2; Khodavardi et al. [26] in district two of Shastkalateh forest from 28 to 1704 m^2; Amiri et al. [19] in district one of Shastkaleteh forest from 40 to 622 m^2; Sefidi et al. [23] in Golband forest from 68 to 3150 m^2, and Mataji et al. [64] in Kheyroud, Noushar from 34 to 579 m^2, were fluctuated. In the current study, the existing gaps were created by the windstorm. Therefore, the severity of the damage to the forest structure was higher than that of other stands, but again, the proportion of the gap size to the total forest area is similar to previous studies (~6%). In most of the broadleaf forests of the Hyrcanian ecosystem, for instance, the surveys of Sefidi et al. [23], Amiri et al. [19], Khodavardi et al. [26], gaps cover less than 10% of the entire region area. Comparing studies beyond the Hyrcanian forests of less resemblance tree species compositions, such as European countries [56,65,66,67], North America [54,68], and East Asia [69,70] which range from 1.4-31%, the intensity of windstorm damage to the stand structure is greater. As a consequence, the gap size created is also greater. The amount presented in this study is very nearly that of the other northern Iran forest stands (up to 9%). Nevertheless, the documented amounts were less than the other temperate ecosystems in the U.S.A., Central Europe, and East Asia. Likely, the cause for the difference in windstorm damage depends on the forest type, stand structure, the composition of tree species, the speed, direction, and duration of the storm, physiographic features, and soil properties [26].

Table 2) Allocation of stands extent according to windstorm damage degree (gap size).

Stand*	Damage degree** (% of the total area according to gap size)				
	Very high	High	Medium	Low	absent
1	28.5	18.4	8.7	4.7	39.7
2	22.4	26.6	6.5	2.8	41.7
3	38.1	15.9	4.2	1.6	40.2
4	41	8.3	3.8	2.5	44.4
5	26.7	7.3	8	5.3	52.7
6	16.7	11.5	4.4	0.9	66.4

*- Dominant tree species: 1= Oriental beech (44.6%), 2= Common hornbeam (38%), 3= Common hornbeam (40%), 4= Oriental beech (45.5), 5= Ironwood (50.6%), 6=Caucasian alder (60.8%).
** Damage degree: Losses in growing stock; very high, <50 % or <1000 m^2; high, 30-50 % or 500-1000 m^2; Medium 10-30 % or 200-500 m^2; Low >10 % or >200 m^2.

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Table 3) Structural characteristics gaps created by windstorms in the studied sample stands.

Stand	Number of gaps in each stand		Gap per hectare mean+ SD*	Gap size (m^2) mean ±SD (m^2)	The sum of the gap size		Min of gap size (m^2)	Max of gap size (m^2)
	N	%				%		
1	117	18.6	4 ±1.32	303 ±114	35575	14.7	20	3000
2	90	14.3	2 ±2.04	283 ±89	25498	10.6	27	2000
3	213	33.8	4 ±1.6	380 ±125	80760	33.5	25	1980
4	151	24	2.5 ±0.6	471 ±207	67768	28.0	28	3500
5	35	5.5	1.7 ±0.82	431 ±257	15086	6.3	40	1600
6	24	3.8	1.6 ±1.3	694 ±308	16667	6.9	23	4150
Total	630	100	-	-	241384		-	-

SD= standard deviation

In small gaps, the least percentage belonged to the sixth stand (29.1%, the dominant species was Caucasian alder), and the highest percentage belonged to the first (56.4%, the dominant species was oriental beech). In contrast, the sixth and second stands in the large gap classes accounted for the highest and lowest, respectively (Table 4). Also, the total area of gaps created by windstorms was 24.14 ha, which covers close to 6% of the sixth forest stands. From the abovementioned value, the proportions of one to six stands were 14.7, 10.6, 33.5, 28, 6.3, and 6.9 percent, respectively. The given proportions are mainly consistent with the findings from Hyrcanian forests in northern Iran [19,23,26,37,71].

The results showed that small (less than 200 m^2) and medium (200-500 m^2) gaps constitute a minimum of 46% in six stands and a maximum of 89% in one stand. Therefore, most of the gaps created by windstorms in the mixed broad-leaved stands belong to these classes. In contrast, only in six sample stands did about 54% of the gaps belong to the 500-1000 and more extensive than 1000 m^2 classes (Figure 4). Similar findings were presented from mixed forest stands in Keyroud and Shastkalateh forests in Caspian ecosystems [19, 23,26]. However, Delfan-Abazari et al. [72] showed that most gaps ranged between 300 to 500 m^2 in the Kelardasht region. We indicated that the lognormal distribution corresponded to the incidence distribution of the gap size in all sample stands. Researchers such as Kucbel et al. [73], Sefidi et al. [23], Petritan et al. [57], Orman and Dobroloska [67], Zenner et al. [35], Khodaverdi et al. [19] and Mattaji and Vahedi [37] have conveyed that the frequency dispensation of gap sizes follow a lognormal in various forest kinds around the world. Although, several other authors have reported a negative exponential form [56]. Our study and Khodaverdi et al. [19] demonstrated that incidents are more likely to be affected by the longevity of trees, wind, and other phenomena in the Hyrcanian region. However, many other studies of mixed forest stands in Europe have shown that episodic severe perturbations due to wind, fire, and/or snow play a vital role in the dynamics of forest ecosystems [67, 74, 75, 76].

The statistical results showed that the oriental beech, hornbeam, Caucasian alder, and velvet maple are involved in all stands as gapmakers. Also, oriental beech gapmakers are between 52.9-70.6% in all stands. At the

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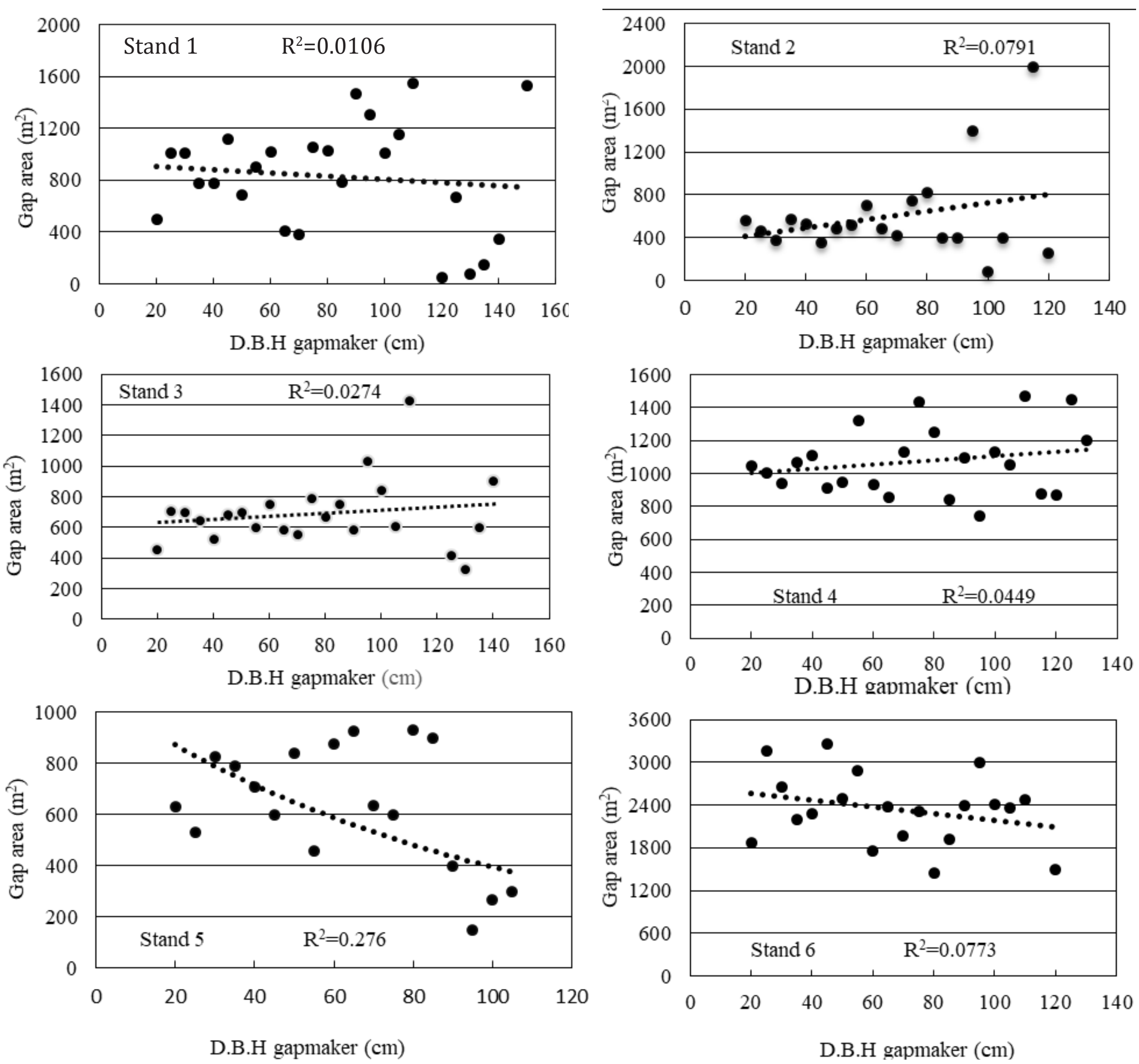

Figure 4) Relevance between the diameter of gapmaker trees and gap size in the sample shows a significant difference between the two variables. Between gap size and D.B.H. gapmakers in the studied stands (Scatterplots of the gap area of dominant tree species: (1) Oriental beech (44.6 %), (2) Common hornbeam (38 %), (3) Common hornbeam, (4) Oriental beech (45.5), (5) Ironwood (50.6 %), (6) Caucasian alder (60.8 %) across different gapmaker D.B.H. (cm).

same time, the hornbeam occupies the most presence of a species as a gapmaker tree in the studied area. In the forest types where oriental beech and hornbeam account for a higher percentage of the stand composition, the relationship between the diameter of gap makers and gap size has a positive and increasing trend. However, in the stands where Ironwood and hornbeam are dominant species, the relationship above is negative, and the curve has a reverse trend. However, the difference between the number of species per stand, the abundance of gap maker's trees, and the gap size created by the windstorm is significant. It seems that species such as oriental beech and Caucasian alder, which have a superficial root system, are more exposed to windstorms. More of these trees are damaged than the Ironwood, hornbeam, and even maple, which have a deeper root system.

Most of the gaps were organized because of one to four tree-fall events in all six stands (>66%), and it was distinguished that eight

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Table 4) Structural characteristics of trees inside each gap class and distribution of gap number in the studied stands according to windstorm damage degree.

The severity of damage (created gap size m^2)	D.B.H. (cm)	H (m)	The number of gaps in the studied stands						F-value	Sig.
	Mean ± SE		1	2	3	4	5	6		
<200	50.12 ± 29.35	26.26 ± 9.30	66	38	77	37	12	8	73.93	0.003
200-500	50.88 ± 27.48	24.43 ± 10.25	30	40	68	43	10	5	116.72	0.052
500-1000	53.21± 34.60	23.82 ± 8.66	14	10	56	41	9	11	54.86	0.002
>1000	55.30 ± 42.73	25.75 ± 9.54	7	2	12	30	4	2	21.75	0.005
Total	-	-	117	90	213	151	35	26	66.81	0.015

*- Dominant tree species: 1= Oriental beech (44.6%), 2= Common hornbeam (38%), 3= Common hornbeam, 4= Oriental beech (45.5), 5= Ironwood (50.6%), 6=Caucasian alder (60.8%). H = tree height; SE = standard error

Table 5) Percentage share of gapmakers by species within studied samples.

Tree species Gap maker (D.B.H >20cm)	Sample stands											
	1		2		3		4		5		6	
	N. of trees	%	N	%	N	%	N	%	N	%	N	%
Velvet maple	10	3.3	21	7.7	49	8.2	36	5.9	3	3.5	11	5
Ironwood	-	-	3	1.1	24	4	8	1.3	2	2.4	11	5
Chestnut-leaf oak	-	-	4	1.5	-	-	-	-	1	1.2	-	-
Caucasian alder	76	24.9	25	9.3	65	10.9	49	8	6	7	23	9.3
Oriental beech	192	62.9	145	53.7	335	56.1	428	70.6	45	52.9	162	65.9
Cappadocian maple	2	0.7	4	1.5	2	0.3	2	0.3	-	-	3	1.2
Date-plum	1	0.3	-	-	11	1.8	-	-	-	-	1	0.4
Caucasian wingnut	4	1.3	1	0.7	5	0.8	5	0.8	-	-	3	1.2
Wych elm	-	-	-	-	1	0.16	5	0.8	-	-	1	0.4
lime	-		-	-	-	-	1	0.2	-	-	1	0.4
Hornbeam	22	7.2	66	24.5	105	17.6	72	11.9	28	32.9	30	12
Total	305	100	270	100	597	100	606	100	85	100	246	100

and nine gap makers formed no gaps in the first stand. In contrast, the sixth stand accounted for about 54% of the total tree falls, more than five gapmakers. Also, we realized that no gap was constituted by nine and >10 gap makers in the fifth stand. Differences in the number and types of gap makers forming the gaps can result from differences in the number and composition of species, the stand structure, and the DBH distribution of the damaged trees in each stand. Studies on pure and mixed forests of

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the Caspian Region have detected that most gaps are organized because of a single tree-fall (more than 50% of all gaps) [19,23,26] and two tree-fall incidents [72,77].

In our study, gaps with one gapmaker do not contribute significantly to the sample stands, so they accounted for only 19.5% of all the six stands, the lowest value recorded thus far for mixed-dominated stands in the Hyrcanian forests (Figure 5). Nevertheless, several surveys have conveyed- for the distribution of gap makers per gap - a reverse J-shaped form, i.e., the maximum frequency of single tree gaps [19,23,26,64,73,78]. In some studies, the windstorm issue has been perused in different types, such as landscape, forest communities, and fallen tree ecosystems. As well as in the current study, the impact of windstorms on the gap structure and gapmakers in forest stands with different compositions and frequencies was investigated. The scales of gaps created by windstorms in space and time characterize the fragmented forest structure

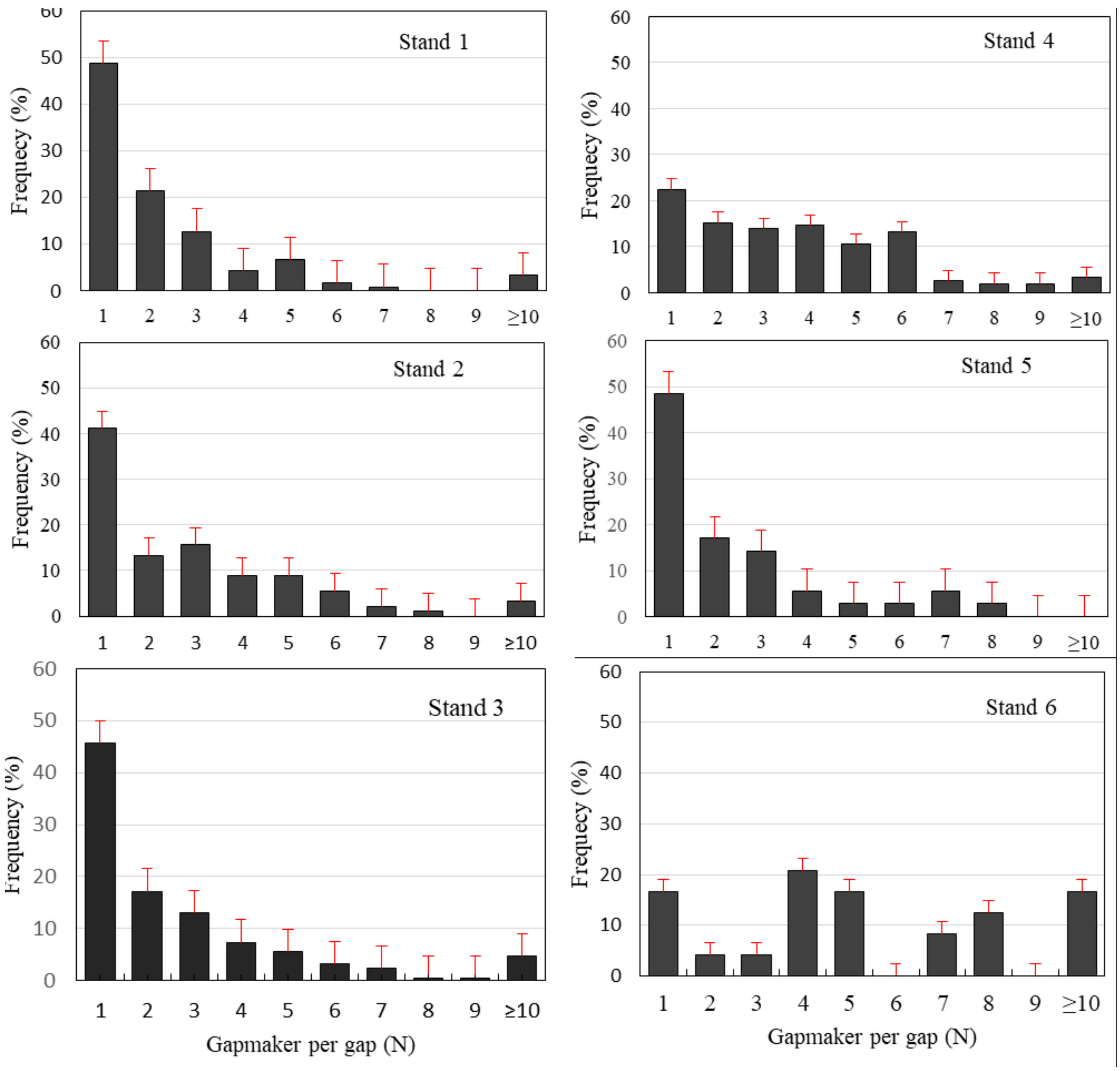

Figure 5) The Frequency distribution of the number of gapmakers per gap in the sample stands (Mean ± Standard deviation). The significant effect for gapmakers per gap within the sample stands considered using the F value.

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communities. The critical consequence of this event is the incidence of gap-phase dynamics in forest stands because the establishment and development of gaps are highly significant for the survival and structural dynamic of broad-leafed species in Hrycanian forests.

Conclusion

Comprehension about primordial forest dynamics is pertinent for their conservation and is an essential reference for depicting sustainable forest management. In old-growth forests, including the Hyrcanian ecosystem, gaps are considered important in forest stand dynamics, mainly when the disorder occurs on small scales and the gaps are closed. Nevertheless, in the current study, the windstorm occurred on a large scale of 653 ha. Although, the severity of the devastation is high in terms of the number and volume of damaged trees. So, the damaged part of the forest allocates 21% of the density and 17% of the volume, but only 6% of the total forest area was much damaged. The studied sample stands were damaged by a windstorm with a speed of 90 km. h in 2015. After that, small and big gaps were created and caused heterogeneity and changes in the forest stand structure. The results confirm that the susceptibility to windstorms depends on the stand structural characteristics such as (species, stand composition, developmental stages, layers story, tree height, the root system, tree crown tendency, and crown area), and the physiographic and soil conditions, including the above sea level, geographical direction, slope, drainage, dryness of the soil. Also, the number and area of gaps the windstorm creates can vary according to the abovementioned conditions. It was determined that the gap sizes in the sample stand with more species (the sixth stand with 11 species) are bigger than those with fewer species (the fifth stand with six species). At the same time, the gap number was higher in the stands with less species diversity (third and fourth stands with 213 and 151 gaps, respectively). Plenty of the destruction from windstorms arose in the upper-slope situations and locations where old-growth forest stands with large crowns, shallow root systems, and full foliage acting as sails in the high winds.

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