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The Impact of Windstorm Disturbance on the Forest Structural Attributes in Oriental Beech-Hornbeam Mixed Stands of Hyrcanian Region

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ABSTRACT

Aims: In this study, the response of individual trees and the stand structure to windstorm damage were investigated in a mixed broad-leaf forest stands located in Darabkola Forest, Sari, northern Iran. A field survey was conducted over an area of 2612 ha of the given stands.
Material & Methods: A full inventory was performed for all trees with diameter at breast height≥ 10cm and all damaged (i.e., snapped, snags, branch loss, broken trunk or uprooted) trees were identified within the study area. Tree height was measured using Laser Distance Meter for trees more than 10 m high and a Clinometer for all trees <10m. The percentage of trees damaged was the dependent variable; but, independent variables included number, mean height (m), total basal area (m^2) and volume trees (m^3). Independent t-test was performed to compare the mean of trees based on diameter classes. Also, the affection of height on susceptibility to windstorm effects was tested by comparing mean trees height within each class.
Findings: The number of the damaged trees varied with species, ranging from 0.04 % (2 individuals) in *Tilia begonifolia* Stev to 53.7 % (2709 individuals) in *Fagus orientalis* L. Among the damaged trees 5054 recorded, 2231 (44.20 %) had been snapped and 787 (15.6 %) uprooted, and 2028 (40.20 %) were snags. Among the species, *Fagus orientalis* L. (47.7 %), *Alnus subcordata* C. A. Mey. (19.7 %) and *Carpinus betulus* L. (18.8 %) were most susceptible to uprooting, whereas *Populus caspica* Bornm, *Quercus castaneifolia* C. A. Mey. and *Ulmus glabra* Huds. were the least susceptible to uprooting. The species differed significantly in their susceptibility to snapping. Trees ≥60cm dbh were more likely to be snapped (78 %) or snags (69 %), whereas trees <60 cm dbh were more presumably to be uprooted (50 %). Also, about one third (33 %) of total trees larger than 60 cm (D.B.H) have showed distinct effects and individual trees >20 m were more commonly uprooted. The number of snapped trees, snags and uprooted trees had a sharp increase in trees taller than 20m.
Conclusion: Our finding showed that Oriental beech and Common hornbeam to be species that were most susceptible to both being snapped and snagged, whereas Caucasian alder had the most uprooting damage among the other species. Overall, features like species, D.B.H, height and height to diameter ratio (H/D.B.H), were intensively related with the type and severity of windstorm damage. The findings showed that windstorms cause substantial structural effects in mixed stands of beech and hornbeam.

Keywords: Individual Features; Natural Disasters; Darabkola Forest; Caspian Ecosystems.

CITATION LINKS

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Introduction

Natural disturbances have a substantial duty in forest formation and determining forest structure and landscape dynamics. These disturbances can further affect species composition, structural characteristics, nutrient cycles, and reallocation of resources, species diversity, and other forest components [1,2,3,4,5,6]. Disturbances are expectable events in all forest ecosystems, changing environmental conditions and affecting evolution and succession processes [2,7]. Forest disturbances are usually characterized based on their severity, spatial extent, and frequency and range from small-scale and frequent (such as individual tree replacement) to large-scale and infrequent windstorms, hurricanes, and fires, considered forest stands destroying events [1]. In other hand, natural disturbances like windstorm, fires, avalanches, snow breakage or insect outburst shape mountain forests globally. However, in numerous areas over the past centuries human activities have strongly influenced forest dynamics [8]. Wind storms are among the major natural disruptions in forest ecosystems. Also, in regions such as European forests, wind storms are the main damaging agent, which was by 1.5 and 2.5 times more than the effect of insects and diseases and the damage caused by forest fires [9,10]. In recent years it is expected that the frequency and intensity of these natural disturbances to surge, like windstorms, due to the global climate change [11,12]. In addition, the amount of wood harvested due to disturbances, like windstorms, accounts for 20% of the total damage in temperate ecosystems and continues to rise [13]. The importance of forest type (i.e., pure *vs*. mixed stand, one layer *vs*. multi-layer stand, and broadleaf *vs.* needle leaf) on the severity of windstorm effects were studied in many habitats [14,15]. However, Boucher et al [16] and Mitchell [17] consider windstorm effects related to standing structural features, including density and canopy height, rather than species' properties. In contrast, Zimmerman et al. [18] Vandermeer et al. [19] reported that damages such as snapping and uprooting trees could differentially affect stand structure. In countries like Puerto Rico, windstorms occur in the expansion of accumulated and uniform stands with short-return periods and thus favor low regeneration and high competition [20,21]. But, in other countries, including Nicaragua, it happens only every few decades and creates areas to establish recruitment seedlings [19]. Kooch et al. (2012) reported wind-throw effects on the biodiversity of the natural forest ecosystem in Mazandaran province, Hyrcanian forests. The diversity parameters were significantly different in canopy gaps areas. The biodiversity indices had an ascending trend with increased canopy gaps areas. The findings showed that wind-throw affects plant communities' dynamics and requires attention in forest management [22].

Many large-scale disturbances have been presented worldwide, particularly in broadleaf forests in temperate ecosystems [23,24,25,26,27,28,29], showing that a better comprehension of disruption regimes in natural forest types is needed. The Hyrcanian forest region is among the forests lacking such data on forest disturbance. The most distinguishing characteristic of this area is a broadleaf deciduous forest, which stretches out from sea level up to an altitude of 2,800 m. It is known through a range of bio-climatic zones with various forest types and annual precipitation varying from 600 to 2000mm [30]. The Hyrcanian forests include 15% of Iranian forests and 1.1% of the country's total area [31,32]. They are typical mountainous ecosystems and have high tree density and volume and relatively old trees. Therefore, it theorized that snapped and uprooted trees in such ecosystems are abundant. Still, so far, insufficient studies have been made about identifying the factors affecting the susceptibility of trees to wind damage. Although studies of forest disturbances have a long history in Europe and other countries, few surveys in the Hyrcanian forests about the effect of storm and wind disturbances on composition and forest structure. Hyrcanian forests have a high genetic, species, and ecosystem diversity [32]. They serve as a refuge for every native plant and animal species. Still, the potential role of natural disturbances like the storm/windfall or snow in these mixed hardwood forests on forest ecosystem functioning has rarely been made. Thus, such studies can conceive the disturbance regimes in some main forest types, such as pure Fagus-dominated and mixed Fagus-hornbeam stands.

The current survey aimed to contribute to the science of the windstorm disturbance in the broadleaf mixed forest stands in the center of the Hyrcanian region, northern Iran, by synthesizing existing information. The research assumption was based on that we characterized post-windstorm tree and stand attributes and composition associated with observed structural effects. Therefore, we asked the following questions:

(1) Is windstorm damage higher in Oriental beech than other tree species in the studied stands?

(2) Is the windstorm damage to large diameter trees greater than smaller diameter classes?

And (3) is the impact of the windstorm on snapped trees more than the other trees damaged (e.g., snags and uprooting)?

Materials & Methods

This study was done in Darabkola Forest with an area of 2612 ha. The Darabkola Forest has situated 15 km to the east of Sari, Mazandaran Province, northern Iran (36° 23′ to 36° 33′ north latitude and 52° 20′ to 52° 31′ east longitudes) on the lower altitudes of a mountain range. Average, minimum and maximum annual temperatures are 16°C, -7.5°C (in January) and 39.1°C (in June), respectively [33]. Annual rainfall is 984 mm, with a signed dry season from June to early September. The soil taxonomic classification is Alfisols and Inceptisols, based on USDA Soil Taxonomy. Soil texture is clay-loam to loam regarding soil profile [34] and likewise has a pH of 6.0-7.5 [36]. The minimum and maximum heights of the district are 160 and 710 m above sea level, respectively. The average slope in most parts of the region is 30 %, and the general aspect is northern (Figure 1). The forest management plan surveys show that the region has limestone bedrock and marl with calcareous sandstone. The research site is covered primarily by mixed broad-leaved species of *Fagus orientalis* L (Oriental beech), *Carpinus betulus* L. (common hornbeam), *and Acer velutinum* Boiss. And *Acer cappadocicum* (Velvet and Cappadocian maple), *Alnus subcordata* C.A.Mey. (Caucasian alder), *Parrotia persica* (ironwood), *Diospyrus lotus* (Date plum), *Ulmus glabra* Huds. (Mountain elm) and minor component of other species (including: *Acer cappadocicum* Gled, *Tilia begoniifolia* Steven, *Juglans regia* L.and *Salix nigra* Marshall). The studied forest stands are often two to three- stories that have a top height of 30 m [34].

In mid-October 2014, a windstorm made landfall between the cities of Sari and Neka in northern Iran (central Hyrcanian Forests, Mazandaran Province). The cyclone moved through the area and converted a low-pressure system over the south and center of Mazandaran province on 16th October (Figure 1). On the day of the windstorm, the temperature was at least 20 and at most 33.5 °C, speed of 30 m.s (108 km.h) with a relative

Table 1) Stand structure and species composition prior to the windstorm in the study site (D.B.H>10cm).

Species (Common name)	Density ($n.ha^{-1}$)	%	D.B.H (cm)	Basal area ($m^2.ha^{-1}$)	Height (m)	Volume ($m^3.ha^{-1}$)	H/D (%)
Oriental beech	86	41.7	47.3	15.1	28.50	175.6	55.6
Common hornbeam	39	18.9	41.5	4.8	28.44	48.8	60.8
Caucasian alder	27	13.1	64.7	2.8	33.40	24.3	83.3
Velvet maple	11	5.3	48.6	1.7	29.60	13.8	70.8
False walnut	2	1	32.5	0.8	22.60	2.8	73.8
Date-plum	6	2.9	15.4	0.9	20.45	5.3	80.3
Ironwood	14	6.8	27.8	2.2	21.30	13.5	47.5
Cappadocian maple	3	1.4	29	0.5	23.20	1.3	70.2
Mountain elm	6	2.9	34	0.8	24.8	10.6	74.6
lime tree	4	1.9	27.6	0.3	21.5	2	64.8
Other species*	8	3.9	29.7	1.1	25.3	14.8	66.8
Total	206	100	-	31	-	312.8	-

humidity of %61 and rainfall of 50.2 mm. The duration of the windstorm was about two days. Also, the windstorm direction was northwest to southwest [35]. The windstorm caused considerable damage to building structures in coastal and mountain communities and affected more than 2612 ha of mixed deciduous forest stands. The weather forecast reports demonstrated that no great windstorms had affected northern Iran. Identically, historical data shows that albeit many temperate windstorms regularly pass over northern Iran, they have not made landfall in this region [37].

Field investigation and data analyses

A field analysis was done so as to identify the properties of every distinctive tree and stand its structural influence on the type and intensity of windstorm damage, during the spring and summer of 2015. Full inventory was carried out over the 653 hectares of damaged forest stands. All identifiable damaged trees (snapped, snags – including; branch loss, broken trunk- or uprooted) were identified in the homogeneous topographical part of Darabkola forest. A total number of 5064 windstorm trees damaged was observed in 25 % of the study area. Table 1 shows some of the structural characteristics and composition species of the Darabkola forest before the windstorm (Table 1).

Also, within five months after the windstorm, all storm-damaged trees ≥10cm D.B.H were determined. Trees damaged in the windstorm based on the freshness of the root biomass and leaves were easily differentiated from older uprooted or snapped trees. We recorded the species, height, and D.B.H for each tree damaged at 1.30 m. Tree height was measured using Laser Distance Meter (Leica Disto D5, Haglöf Sweden) for trees more than 10 m high and a Clinometer (Haglöf EC II, Haglöf Sweden) for all trees <10m. Windstorm effects were registered as snapped, snags (including lost branch, broken trunk), and uprooted. A tree was regarded as having "branch loss" when branches larger than 10 cm in diameter

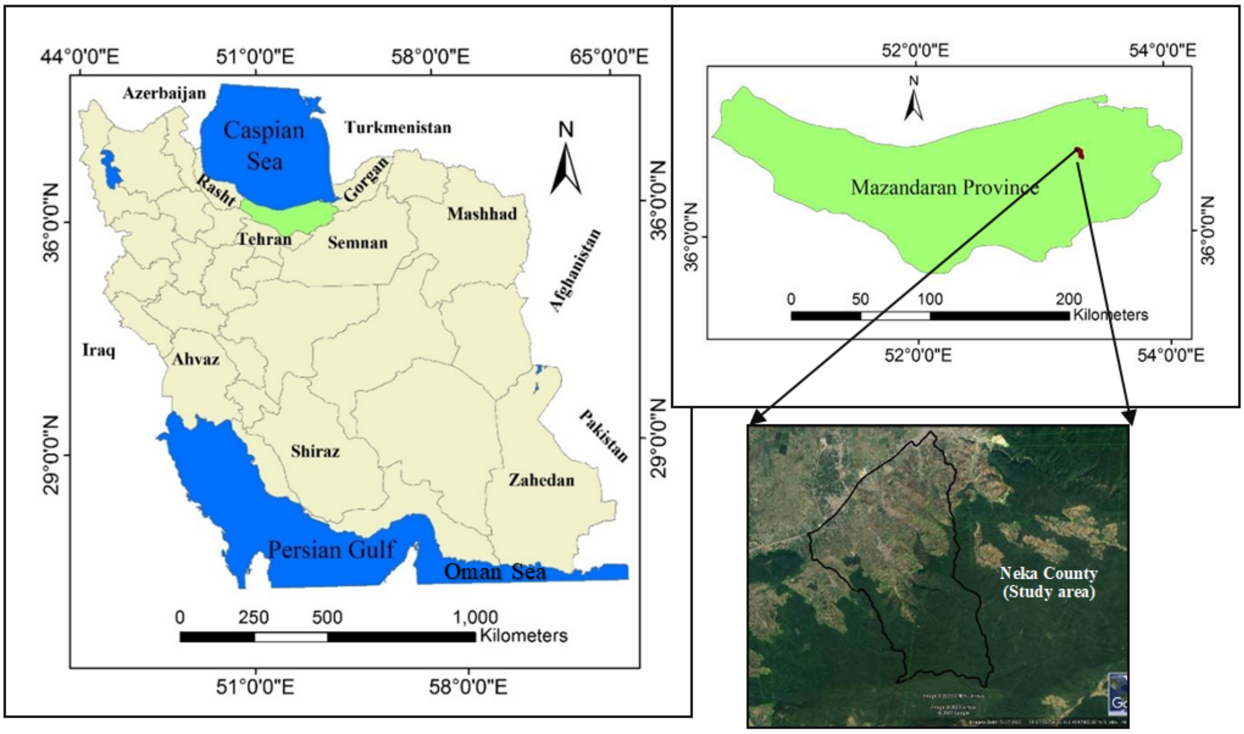

Figure 1) the study region: Darabakola Forest, Mazandaran Province, and its location within Hyrcanian Forests, North of Iran.

were broken or the trunk displayed scars from broken branches.

Data Analysis

The independent t-test was performed to compare the mean of trees based on diameter classes. Also, the influence of height on vulnerability to windstorm effects was tested by comparing mean trees height within each effect class. We compared the number of trees that experienced structural effects (snags, snapped, and uprooted). Subsequently, to compare the means of trees by size class were conducted Unequal variance t-tests. The influence of height on susceptibility to windstorm effects was tested by comparing mean tree height within each class [6]. One-way analysis of variance (ANOVA) was used to compare the statistical significance of differences in the median heights among classes; pairwise comparisons were made with Tukey's test. All analyses performed using the SPSS version. 20 (IBM Corporation) after being visually assessed for normality.

Findings

In total, 15 species were identified. Mixed broad-leaved stands were dominated by Oriental beech, common hornbeam, and Caucasian alder and had some commercially valuable species, including chestnut-leaved oak, lime tree, and velvet maple (Table 2). The number of the damaged stems >10cm D.B.H was 5045 stems in the study area. The damaged trees varied across species, ranging from ~0.04 % (2 individuals) in lime to 53.7 % (2709 individuals) in Oriental beech. The mean D.B.H of trees damaged was 52cm, and Oriental beech with 58cm and Date-plum with 29.2 cm had the maximum and minimum D.B.H, respectively (F=126.4, P-value=0.002). The total basal area was 1163.2 m^2 for all trees damaged in the 653 ha. About 75 % of the total trees damaged were ≥20 m tall. The results showed that more than two-thirds of the volume of trees damaged was made up of Oriental beech (Table 2). There were measurable differences in number per hectare and tree

Table 2) some structural characteristics of trees damaged after windstorm in the study area.

Type of damaged	Total frequency		D.B.H (mean)	Basal area	Height (mean)	Total Volume	
	N	%	(cm)	(m^2)	(m)	m^3	%
Snapped	2230	44.2	48.15	410.23	24.73	5828.6	35.2
Snag (branch loss, broken trunk)	2028	40.2	52.39	481.51	24.87	6680	40.4
Uprooted	787	15.6	62.42	271.47	27.21	4035.1	24.4
Sum or mean		100	54.32	1163.2	25.60	16543.7	100
F value	36.87	-	123.64	19.45	94.55	27.86	-
Sing	0.001	-	0.02	0.005	0.01	0.00	-
Damaged	5045	8.8	54.32	1163.2	25.60	16543.7	12.74
Undamaged	52680	91.2	38.54	17447.3	22.82	113217	87.26
Total (damaged and undamaged)	57725	100	-	18610.5	-	129760.7	100

* Cappadocian maple, Begonia-leafed Lime, Common walnut and Black willow

Table 3) some of the structural characteristics of trees damaged in the study area based on the type of damage.

Species	Frequency		D.B.H (cm)			Basal area (m^2)	Height (m)	Volume (m^3)	H/D (%)
	(N)	%	Mean	Min	Max				
Oriental beech	2709	53.7	58	20	150	791.4	27	12097.3	56.7
Common hornbeam	1117	22.1	47	20	130	185.7	23.4	2333.87	67.6
Caucasian alder	492	9.75	42	20	130	77.5	22.9	826.34	90.3
Velvet maple	267	5.3	46.1	20	140	49.2	23.5	551.06	74.1
Ironwood	243	4.8	40	20	115	21.8	17.9	283.5	48
False walnut	33	0.7	42	20	90	5	22.6	55.91	73.9
Date-plum	44	0.9	29.2	20	50	1.8	16.9	21.62	82.9
Cappadocian maple	22	0.4	49	20	100	4.3	24.1	49.5	68.5
Mountain elm	16	0.3	33	20	75	1.6	20.9	16.7	73.2
lime tree	2	0.04	37.5	20	55	0.3	21.5	2.971	60.3
Other species*	100	2	45	20	140	25.4	22.3	306.3	69.7
Total	5045	100	52	20	150	1163.2	25.22	16544.27	-

* Begonia-leafed Lime, Common walnut, Black willow and Green briar.

size (height and H/D) between Oriental beech and other species affected by the storm. Oriental beech comprised over 2700 trees with a volume of 12097m^3, and beech stands had a lower average H/D ratio than species such as hornbeam, Caucasian alder, and Velvet maple (Table 2).

Among the 57725 trees recorded, 5045 were damaged trees -2230 trees (44.20 %) had been snapped, 2028 (40.20 %) and 787 (15.6 %) uprooted- and 52680 not damaged. The basal area of the damaged snags (481m^2) was higher than that of the snapped trees (410.23 m^2) overall. Thus, the basal area was statistically different among snapped, snags, and uprooted tree damaged classes (P < 0.002, Table 3). The average D.B.H of uprooted trees was more than the snapped trees and snags (P<0.001; Table 3). Although the mean D.B.H values of the snapped, snags, and uprooted were different, data on heights would be required to fully assess the effect of tree size on susceptibility to windstorm damage. Because the fallen or broken remnants of the tops of very trees only allowed approximates of minimum diameters. The result of this study showed that the maximum volume was allocated to the snags (6680 m^3, 40.4 %) caused by the windstorm, and there was a statistical difference in volume among snapped trees, snags, and uprooted trees (P<0.001; Table 3).

The D.B.H distribution of the damaged trees exhibited a reverse J or L-shape distribution. But, the volume distribution in diameter classes of trees damage was bell-shaped. Distribution of number in the diameter classes in the overall damaged trees indicated that the highest Frequency was dedicated to the diameter classes 30 and 40 cm (about 9 %), and the lowest Frequency was belonged to diameter classes of 140 cm (>1 %). Also, the highest volume of trees damaged by the windstorm occurred in the diameter class 75 cm (Figure 2).

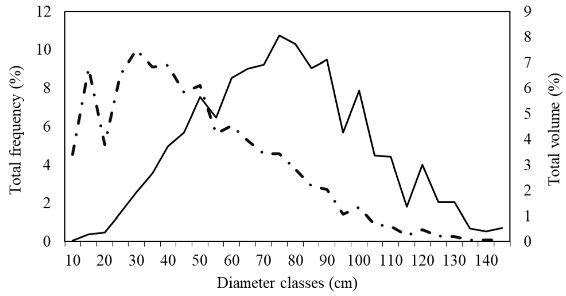

Figure 2) Distribution of the number (interrupted line) and volume (Continuous line) of damaged trees in the diameter classes.

Figure 3 shows differences in the sensitivity of species to windstorm damage for canopy trees. As Frequency of uprooted trees in each category were high. Among the trees, Oriental beech (47.7 %), Caucasian alder (19.7 %), and hornbeam (18.8 %) were most susceptible to uprooting, whereas Caspian poplar, chestnut -leaved oak, and mountain elm were the least vulnerable. Species differed significantly in their susceptibility to snapping (Figure 3). Among trees damaged, Oriental beech (63.2 %) and hornbeam (22 %) were overall more susceptible to snapping than other species. Ironwood had an increased number of snags among canopy trees compared to uprooting and snapped trees (Figure 3).

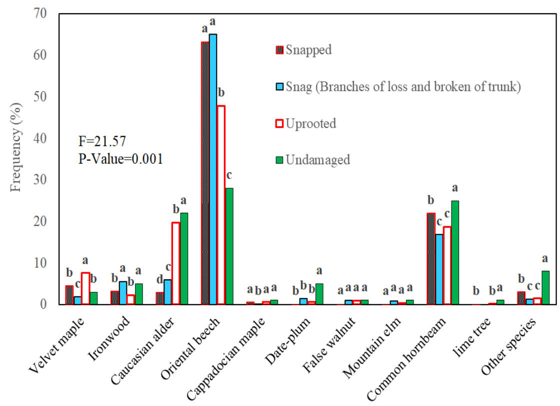

Figure 3) Percentage of species snapped, snagged, uprooted and undamaged after windstorm damage in 2014 (Other species: Caspian poplar, Black locust, Chestnut-leaved oak, Siberian elm and Green briar).

To compare rate of damaged trees based on the damage (snapped, snagged, or uprooted) in different diameter classes indicates size can influence the susceptibility to the kind of windstorm damage. Trees ≥60 cm D.B.H were more likely to be snapped (78 %) or snagged (69 %), while trees <60 cm D.B.H were more probably to be uprooted (50 %) ($P < 0.001$; unpaired t-test, Figure 4). About one-third of the trees (30 %) larger than 60 cm (D.B.H) showed visible damage effects. Also, the D.B.H distribution of snapped trees and snags exhibited a reverse J or L-shape distribution. In contrast, the distribution in diameter classes of trees uprooted was bell-shaped (Figure 4).

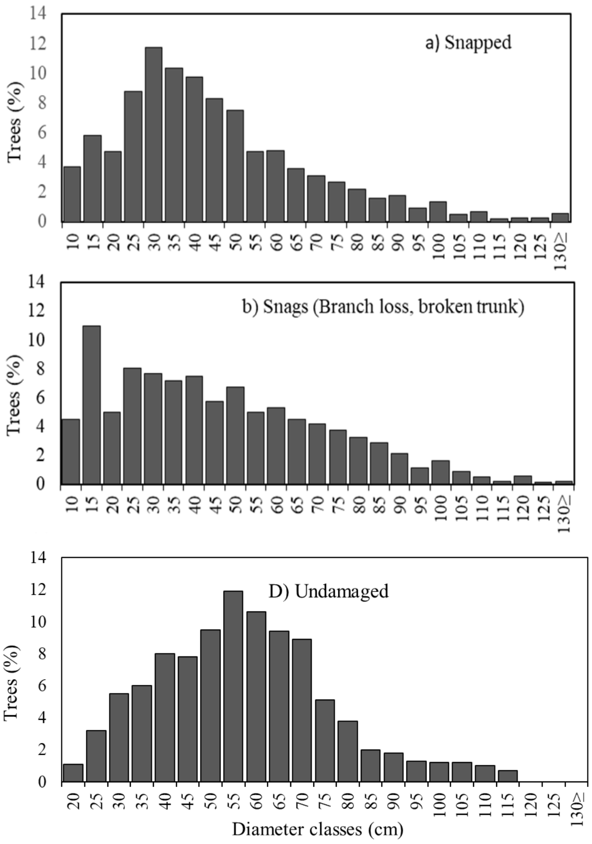

Figure 4) Percent of wind influenced trees arranged by D.B.H size classes in mixed broad leaved stands. Trees >80 cm D.B.H were most probably to be uprooted than snagged or snapped ($p < 0.001$; unpaired t-test).

The number of snapped, snagged, and uprooted increased dramatically for trees taller than 20 m ($p < 0.001$; unpaired t-test, Figure 5). These results showed that windstorm efficacy was also related to tree height and had different results based on damaged type. Comparably, differences in the mean height were determined among all classes except uprooted compared to branch loss. The number of snapped trees was not related to D.B.H or height. Differences in sensitivity to windstorm damage between different sizes of trees were studied by comparing the mean heights of the trees within each snapped species. For all 15 species, uprooted trees were remarkably taller than those snapped or snagged (Figure 5).

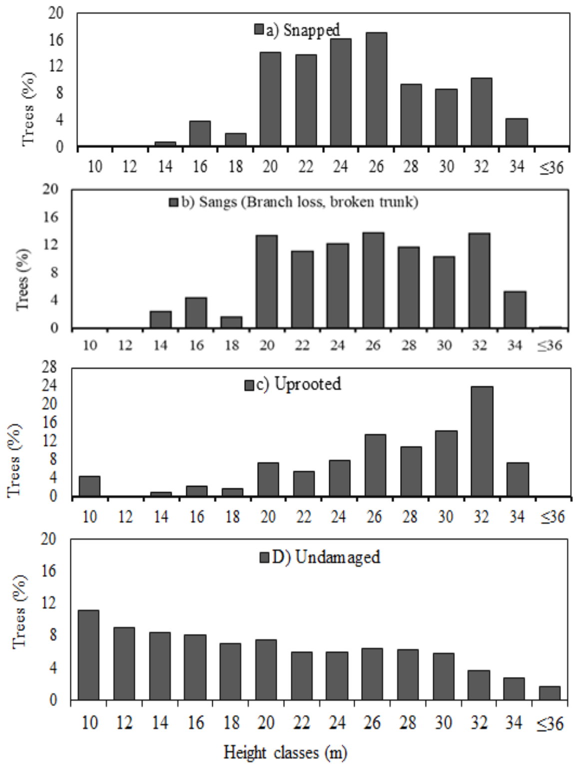

Figure 5) Percent of windstorm influenced trees categorized by height classes. Snags and snapped trees were more abundant among trees >20 m ($P < 0.001$; unpaired t-test). Trees above 26 m more increased uprooted ($P < 0.001$; unpaired t-test). Median height varied remarkably among all classes damaged by the windstorm except <14m ($P < 0.012$, one way ANOVA).

Discussion

The current survey was conducted in a mixed broad-leaved forest in the Hyrcanian region, northern Iran. Generally, to understand the amount of windstorm damage to forests, studying and inventory the affected areas is necessary. Concerning the windstorm in the Darabkola forest, the impact was in an extensive area consisting of many throw trees (about 25% of the total area). Some studies have demonstrated that their size and dimensions influence trees' vulnerability to windstorm damage [6,38,39,40,41]. The results of the mentioned studies are in agreement with our research. Moreover, in some studies the data revealed that value and type of the damage varies considerably between trees with the same site conditions. Moreover, few other data pointed out a significant difference in the amount and type of damage among trees of stands with the same site conditions. This showed that the pattern of windstorm damage is meaningfully dependent on species composition and the structure of stands [28]. Some surveys illustrated that factors such as local wind climate and precipitation, physiography (altitude, aspect, slope, and exposure), soil condition (drainage, root architectures, and system), and stand structure features inclusive tree species, spacing, H/D.B.H ratio, age, and tree size are influential in the occurrence of windstorms [29,42,43,44,45] and silvicultural operations [42,45]. However, because the factors are closely related, it would be difficult to determine which factor is causing the most windstorm damage. Also, some studies suggested differences in windstorm sensitivity among species based on field studies. For example, Savill [46] determined that spruce, pines, and firs were more wind-damaged. Wolf et al. [47] investigated the different fracture types among tree species. Isamoto & Takamiya [48] in Japan observed that species such as hinoki cypress be prone to uprooted when bearing wind damage. In the present study, the lowest percentage of the types of damage was uprooted trees (15.6%). In contrast, the highest percentage was snapped trees (44.2%) and suggesting that trees in our forest were more susceptible to being snapped than uprooted. One of the more severe snapping damage is the lower diameter of these trees compared to others of damages snagging and uprooting. Peltola et al. [49], Achim et al. [50], Rossi et al. [6], and Li et al. [29] achieved similar results compared to our study. Generally, the spatial pattern of damage is influenced by biotic (e.g., species, stem size, canopy structure, density) and abiotic factors (e.g., previous disturbance, physiography, and soil properties).

When the windstorm happened due to the soil being dry with low humidity, trees tended to be snapped and broken than uprooted. This increases trees' root system resistance to uprooting [6]. In other words, the water content of the trees in the temperate ecosystems is relatively down in early autumn when the windstorm takes place, which in turn motivates the branches and the crown of the trees to be more fragile and easily snapped [51]. Thus, this happens mostly in small-diameter trees. Tall and large trees were more vulnerable to uprooting by wind damage than small trees. In contrast, medium diameter classes and intermediate canopy trees are at greater risk to be bent or snagged. This may be because of wind pressure on the crown of canopy trees, as medium diameter trees are a refuge [52]. Rossi et al. [6] proposed that the relationship between dimension and susceptibility to windstorms has been linked to a "sail effect," as large canopies exhibit a greater surface to the wind. This issue has also been confirmed in other studies [53,54,55] (Table 2). Also, this study recommends that tree form and architecture can influence windstorm damage, however these hypothesis are yet to be absolute. Because our surveys were constant at the stand, i.e., canopy trees in the same stand experienced resembling effects. Additionally, crown size, was found to be more dependent on growing conditions than the species architecture. For example, emergent trees such as Caucasian alder and Velvet maple were probably uprooted because of their large canopy size rather than crown architecture. Finally, the relationship between tree size and windstorm susceptibility is accompanied by observations in other locations.

The findings of this research was persistent with the group located inside the strand, so that canopy trees have similar effects in the same stand. Also, crown size was more affiliate on the growing conditions than the species form. For example, emerging trees, such as Caucasian alder and Velvet maple, were likely uprooted because of their large canopy size rather than crown architecture. Eventually, the communication between tree size and storm sensitivity corresponds with observations in other situations. Rossi et al. [6], Foster & Boose [54], and Mitchell [17] (1995), in their study, confirm the results of our survey via the above reasons. The findings indicated that the highest damage rate was small diameter classes (20, 30, and 35 cm D.B.H). These trees are often tall but have thin trunks and light canopy crowns. Therefore, they are more susceptible to windstorm damage than large and very large trees.

Few literatures revealed that the risk of windstorm damage increases with increased density and standing volume [29,55]. The studies forest stands had two to three stories and were mixed broadleaves. In several studies, multi-storey stands are, in general, less exposed to destruction than single-story stands [57], in another study in the Hyrcanian forests, Jafari [37] (2008) has found that uneven-aged and old-growth forests are less sensitive to damage than even-aged forests. In contrast, Persson [58] and Fridman [59] mentioned that even-aged stands, single-story, are more susceptible to damage than multi-aged stands. In the DarabKola forest influenced by the windstorm in 2014, nearly 53% of the stocking volume and 31% of the density consisted of Oriental beech [34]. Hence, the large damage in Oriental beech is not unexpected. Schütz et al. [24], Albrecht et al. [60], and Valinger & Fridman [61] reported that the proportion of a dominant species (nearly pure) in a stand the increased hazard of wind damage. Our findings show that dominated stands by Oriental beech and Caucasian alder are at more danger than dominated stands by common hornbeam and velvet maple, and other species. Furthermore, when Oriental beech exists in mixed stands, the risk of windstorm damage increases with the proportion of Oriental beech. Conversely, an increased proportion of other broadleaf trees such as Velvet maple, Ironwood, and Hornbeam in a stand dominated by Oriental beech decreased the probability of windstorm damage.

The results showed that trees with an H/D.B.H ratio of less than 55 % have higher sustainability to windstorms in the study area. Trees like chestnut oak, ironwood, and green briar have lower F/D.B.H ratios and have the highest resistance against the windstorm. In contrast, oriental beech, common hornbeam, Caucasian alder, and velvet maple were less resistant to damage due to their higher H/D.B.H ratio (Tables 1 and 2). Cremer et al. [62], Wood [63], Mohammadi et al. [30], and Charkazi et al. [64] Also indicated that trees with low H/D ratio had higher persistence to the windbreak. However, Schütz et al. [24] reported no considerable effect of H/D.B.H-ratio on the vulnerability to damage. In our study, H/D.B.H-ratio had a relatively low effect on the possibility of windstorm damage, but species harvested within the last years were more sensitive to damage. Wallentin

& Nilsson [65], in the Norway spruce, stands, showed that thinning increases storm and snow damage. In the current research, the probability of damage decreased with fewer trees per ha having dbh >120cm (Figure 4). The possibility exist because such stands had been thinned or cut a sufficient number of years ago to regain stability [61,66]. Our findings indicated that windstorm effects were influenced based on types of damage by tree size. So that large and very large D.B.H and height increased sensitivity to uprooting. In contrast, small and medium D.B.H and height increased susceptibility to snapping and snagging. Also, light wood density pioneers such as date-plum and chestnut-leaved oak represented low uprooting and mortality (<2 % trees). Large hardwood species inclusive of Oriental beech, common hornbeam, Caucasian alder, and velvet maple experienced higher levels of uprooting, snapping, and snagging (>12 %; Figure 2)

Conclusion

The present study in the Darabkola Forest occurred after an intense windstorm in autumn 2014 when 25 % of the total forest area was damaged. The most severe damage occurred in oriental beech (53.5 %) and hornbeam (22.2 %) forests and revealed the mentioned tree species to be more susceptible to snapping and snagging. Caucasian alder faced more uprooting damage compared to other species. The study emphasizes the windstorm effects on the composition and stands structure in a mixed broad-leaved forest. Due to recent windstorms and current stand conditions in the Hyrcanian region, the wind storm damage venture can be anticipated to increase gradually. Also, in this study determined that increased the ratio of trees after a system change from shelterwood system to a thinning selection system adopted silvicultural will reduce the hazard of wind damage during autumn and winter windstorms. The findings recommended that windstorm effects appertain more on tree size and canopy situation than on species characteristics. Indicators such as tree species, D.B.H, H/D ratio, root system depth, crown size, and site conditions can be useful indicators of the type and intensity of windstorm damage.

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