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Research Article / Araştırma Makalesi

Pre- and Post-Windstorm leaf area index of *Carpinus betulus* trees in an urban forest patch

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Abstract: Natural disturbances are rather rare for the urban forests compared to the anthropogenic ones. However, forcible natural impact may be substantially destructive such as severe storms. Instantaneous defoliation is one of the significant signature of the storm severity. A multipurpose vegetation parameter, Leaf Area Index (LAI) is used as an indicator of instantaneous defoliation which may occur as a result of immediate leaf fall jointly with the stem and branch breakages or uprooting. Enhancing the idea, LAI of the *Carpinus betulus* trees were analyzed before and after the devastating storm in Balamba urban forest patch of Bartın Province at the northwestern of Turkey. The maximum speed of the severe storm was 117 km/h and enough to destruct the trees. Consequently LAI ceased 24% as a result of instantaneous defoliation both in recreation and control sites indicating the severity of damage. Southwester which is associated with heavy rainfall and represent the winds with maximum speeds in the region led to this change. The inexistence of extraordinary meteorological data before and after the severe storm indicates that the wind speed was the main reason for such damage. The same percentage of LAI decrease within the recreation and control sites supports the situation that the soil compaction due to recreation has no definite influence on the severity of windthrow. Scattered pattern of annual maximum wind speeds particularly for the last fifteen years are possible to be the implications for climate change.

Keywords: Maximum wind speed, LAI, hemispherical photograph, European hornbeam, climate change

Bir kent orman parçacığında *Carpinus betulus* ağaçlarının fırtına öncesi ve sonrası yaprak alan indisi

Özet: Kent ormanları için, doğal tahripler insan kaynaklı tahriplere nispeten daha nadirdir. Bununla birlikte, şiddetli fırtınalar gibi etkili doğal afetler aslında yıkıcı olabilir. Ani yaprak dökümü, fırtınanın şiddetini ortaya koyan önemli işaretlerden biridir. Çok amaçlı bir bitki örtüsü parametresi olan Yaprak Alan İndisi (YAİ), gövde, dal kırılmaları ve kök sökülmesi ile birlikte cereyan eden yaprak düşmesinin bir sonucu olan yaprak dökümünün göstergesi olarak kullanılabilir. Bu fikir çerçevesinde, Türkiye'nin kuzeybatısında yer alan Bartın İl'ine bağlı Balamba kent orman parçacığında, şiddetli fırtına öncesi ve sonrasındaki *Carpinus betulus* ağaçlarının YAİ analiz edilmiştir. Şiddetli fırtınanın maksimum hızı saatte 117 km olup, ağaçları harap etmeye yetmiştir. Dolayısıyla, ani yaprak dökümünün bir sonucu olarak, hem rekreasyon hem de kontrol alanlarında YAİ, zararın şiddetini ortaya koyarcasına %24 azalmıştır. Yoğun yağışla özdeşleşen ve bölgede maksimum hızlara sahip rüzgârları temsil eden lodos, böyle bir değişime yol açmıştır. Şiddetli fırtınanın öncesi ve sonrasında olağanüstü meteorolojik verilerin görülmemesi, rüzgâr hızının böyle bir zararın temel sebebi olduğunu ifade etmektedir. YAİ'nin hem rekreasyon hem de kontrol alanlarında eşit oranlarda azalması, rekreasyona bağlı toprak sıkışmasının rüzgar devriği üzerinde herhangi belirgin bir etkisinin olmadığının göstergesidir. Yıllık maksimum rüzgâr hızlarının bilhassa son on beş yıl içerisindeki dalgalanması muhtemel iklim değişikliğinin alametleridir.

Anahtar Kelimeler: Maksimum rüzgâr hızı, YAİ, yarıküre fotoğraf, Avrupa gürgeni, iklim değişikliği

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1. INTRODUCTION

Besides fire and insects, windthrow is one of the most destructive but relatively rare natural disturbances which forest trees are faced with (Waring and Running, 2007). Many researchers have investigated the forest and tree damage due to windthrow. Some of those concentrated on the acute effects whereas the others on chronic effects (Mitchell, 2013). The ones which studied acute effects (e.g. for forests by Rich et al., 2007, Kane, 2008, and for savanna trees by Cook et al., 2008) generally focused on the stem damages, branch failure, bark strip and defoliation based on the decline in the quantity of these organs or the uprooting based on the number of fallen trees. The chronic effects of wind damage cover both the physical disturbances and the forest ecosystem alterations spreading along the subsequent years (Ulanova, 2000). Those long term physiological and ecological impact analyses are largely associated with hurricanes as indicated in the literatures namely by Sherman et al. (2001) and Xi et al. (2008) who concentrated on regeneration performance of vegetation due to gap dynamics. The studies by Boose et al. (1994), Boutet and Weishampel (2003), Kupfer et al. (2008) are the ones which analyzed the ecological effects of winds and hurricanes in landscape scale. Peterson (2000) early mentioned about both the acute and chronic effects relating these immediate and long term impacts to climate change. Moreover, Peltola et al. (2010) investigated the climate change impact on timber production and associated wind-induced forest damages. Although numerous biotic and abiotic factors are effective in wind induced forest disturbance (Everham and Brokaw, 1996), the severity of the wind damage on trees is largely dependent upon wind speed (Gardiner et al., 2000). According to the wind classification and terminology system proposed by the World Meteorological Organization-WMO, the winds are generally termed as blow, breeze, gale, storm, severe storm and hurricane based on their speeds ranging from 2 to 150 km/h respectively (Türkeş, 2010). Hurricanes are tropical cyclones associated with heavy rains which particularly threaten the coasts of USA (Chapman et al., 2008). Defoliation is one of the most common effects of hurricanes (Lugo, 2008). Severe storms are the ones with speed below 117 km/h (Türkeş, 2010) and can also gain the kinetic energy capacity in order to change the forest and canopy structure by leading to stem breakage and defoliation. Instantaneous defoliation is associated with maximum daily wind speed (Beard, 2005) causing stem, branch breakages and even uprooting which in turn account for the leaf fall. Leaf Area Index (LAI) is a significant vegetation parameter defining the one-sided area of the leaves over the projected crown area of a broadleaf vegetation (Bonan, 2008; Kara et al. 2011) and can be used as a signal for windthrow. The usage of LAI as an indicator of wind induced defoliation is restricted to few studies such as Herbert et al. (1999) who analyzed the ecological effects of hurricane by comparing LAI values before and after the hurricane and Wang et al. (2010) who diagnosed severity of forest damage by using satellite vegetation data including the LAI. Urban forests are more susceptible to anthropogenic disturbances rather than naturals. Specifically, recreational urban forests are prone to fire risks (Jestaedt, 2008) and environmental stresses involving the water and nutrient availability problems due to human induced soil compaction (Sieghardt et al., 2010). On the other hand, unlike the woodlands, urban forests possess specific microclimatic conditions (Oke, 1989) which might expose them to natural disturbances such as invasion by insects due to temperature increase and as damages due to wind intrusion throughout more open spaces (Lehvävirta, 2007).

In this study, we attempted to demonstrate the immediate impacts of windthrow particularly the defoliation based on the calculations of LAI for the *Carpinus betulus* trees in Balamba urban forest patch. Wind speeds were also embedded in this study to manifest the influence of the maximum. With maximum speeds of up to 117 km/h, severe storm originated from south-southwestern directions (TSMS, 2013) destroyed some of the buildings and trees in Bartın city center and vicinity where vegetation is mainly in the form of urban forest patches. Consequently, the roofs, windows, lightening equipment and trees were damaged by the storm which lasted for half an hour in August 12^{th} of 2012.

2. MATERIALS AND METHODS

2.1 Balamba Urban Forest Patch

Balamba urban forest patch (Figure / Şekil 1) is located about 3 km away from Bartın city center at the northwestern of Turkey (Öztürk and Bolat, 2012). The patch surface is near flat (less than 10% gradient) with average altitude of 30 m. The patch covers approximately 11 ha and is covered with European hornbeam (*Carpinus betulus*) trees of which canopy closure is higher than 70%. There are multi-aged European hornbeams in the patch where mean diameter at breast height (dbh) are 14 cm and 28 cm for the young and mature trees respectively (TGDF, 2011). The height of the trees ranges between 19 m and 23 m (TGDF, 2011). Few old oaks (*Quercus robur* L.) have been eliminated from this patch in time clued by their dead remnants (Öztürk et al., 2015). Brown forest soil (TMFAL, 2005) has formed on calcareous parent material (TGDMRE, 2007). Settlements are neighbor to the western and southern borders of the patch whereas agricultural areas are near the eastern and northern borders of the patch.

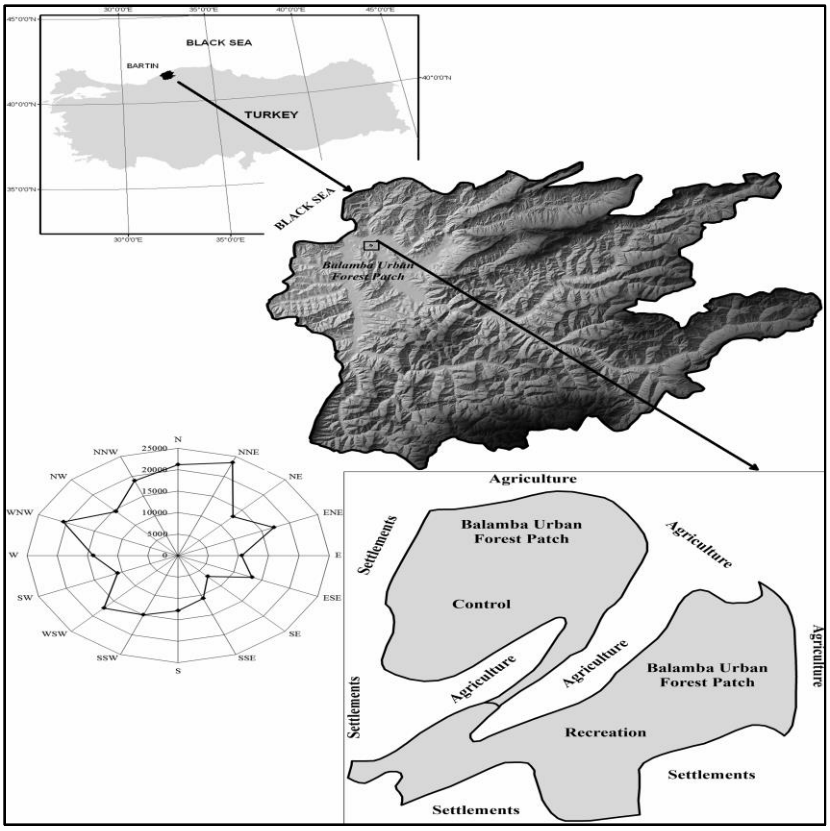

Figure 1. Location of the Balamba Urban Forest Patch within Bartın watershed of Turkey. Wind directions based on the number of blows (TSMS, 2013).

Şekil 1. Balamba Kent Orman Parçacığının Bartın Havzası ve Türkiye içerisindeki konumu. Esme sayılarına bağlı olarak rüzgâr yönleri (TSMS, 2013).

According to the management plans of Turkish General Directorate of Forestry, the patch was proposed to be managed in order to public recreation (TGDF, 2011). However, northern part (~5 ha) of the patch is barriered to restrict entry inside which remains relatively unspoiled. The other part (~6 ha) of the patch is utilized by the citizens particularly for the picnic activities from late spring until the early autumn. On the other hand, the period from late autumn until the early spring is when the people visit the patch for passive recreation such as resting. Therefore, the patch is subjected to soil compaction (Kara and Bolat, 2007) particularly in summer rather than in winter. Besides, the trees are exposed to fire smoke during the picnic activities in summer. Consequently, the patch is susceptible to the anthropogenic disturbances rather than natural ones.

According to the 30 years data (1982-2011) from the meteorological station which is about half kilometer away from the patch, average annual temperature is 12.6°C whereas average annual precipitation is 1044 mm mainly in the form of rainfall (TSMS, 2013). The region drops into humid mesothermal climate regime (Atalay, 2011). The hottest month is July with mean temperature of 22.2°C while the coldest month is January with mean temperature of 4.1°C. The wettest month is October with mean precipitation of 123 mm while the driest month is May with mean precipitation of 49 mm. Dependent upon the duration, the prevailing wind direction is from west-northwest and north-northeast where Black Sea is situated (Figure 1). Average annual wind speed is 5.4 km/h. The mean wind speed is the highest for July with 6.6 km/h while the lowest for December with 3.8 km/h (Figure / Şekil 2). On the other hand, According to the Figure 2, it can be understood that western and northwestern winds prevail the first half of the year; from January until May whereas particularly northern and northeastern winds dominate the second half from June until December.

Southwester is a cyclonic wind introduced into the western and southern regions of Turkey through Balkans and Mediterranean Sea mainly in the form of severe storms (Türkeş, 2010). Balamba urban forest patch with almost flat surface and relatively open periphery was subjected to instantaneous severe windstorm which ultimately ceased abandoning stem, branch, bark, trunk debris and scattered leaves behind. Namely, some of the trees were uprooted whereas the others suffered stem and branch breakages. Those debris and fallen leaves were of *Carpinus betulus* trees which is a deciduous species with about 5-10 × 3-5 cm dimensioned ovate and acute leaves and with smooth grey bark, grooved trunk below (Davis, 1982). The approximately 25 m tall tree spreads whole Europe, extending throughout northwestern and northern Turkey reaching far to Caucasia and Iran (Yaltırık, 1993).

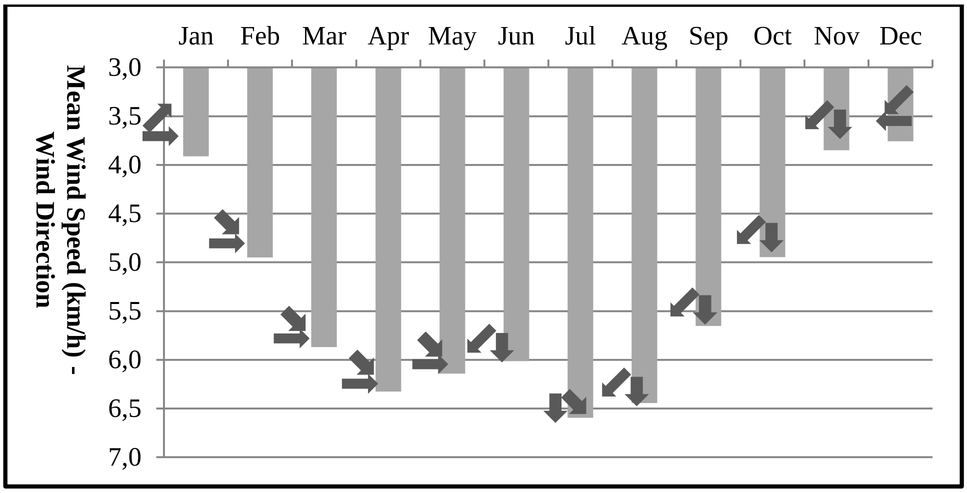

Figure 2. Monthly mean wind speeds (km/h) together with their weighted directions.
Şekil 2. Aylık ortalama rüzgâr hızları (km/saat) ile bu hızların hâkim yönleri.

2.2 Hemispherical Photographing

These injuries combined with the immediate blow on the canopy interface led to a part of defoliation which in turn resulted in LAI decline. Our instantaneous defoliation assessment in Balamba urban forest patch is based on the LAI observation before and after the severe storm. The change in the area index of *Carpinus betulus* leaves before and following the severe storm was determined by taking and analysis of hemispherical (180°) photographs in the Balamba urban forest patch. Using Sigma 8 mm fisheye lens mounted on a Canon EOS 5D digital SLR camera, hemispherical photographs of the European hornbeam canopies at nine points were taken. Six of those nine points were from recreation site whereas three points were from control sites. Hemispherical photograph analysis technique with Hemisfer software 1.5.3 version (Swiss Federal Institute for Forest, Snow and Landscape Research (Schleppi et al., 2007) was performed for processing digital photographs taken. Based on the study of Nobis and Hunziker (2005), automatic thresholding was used during the digital photograph analysis. Lang (1987) method was preferred for the analysis of the LAI. Corrections of both Schleppi et al. (2007) for the non-linearity and slope and Chen and Cihlar (1995) for the clumping effect were integrated into calculations to avoid the influences of tree organs other than the leaves such as stems and branches on the values of LAI. Eventually, two field visits for photographing were carried out involving the pre-windstorm; August 1st, 2012 and the post-storm; September 1st, 2012. Consequently, 2 field visits to each 9 points resulted in total 18 hemispherical photographs.

3. RESULTS

Immediate decrease in the LAI which exceeds the natural defoliation based decline suddenly occurred after the severe windstorm. Accordingly, inspection of the results does involve the maximum wind analysis. Therefore, initial comprehension of the annual maximum wind speeds solely will provide insight into the instantaneous defoliation phenomena within the urban forest patch. Hence this is followed by the evaluation of the LAI values before and after the windstorm. Ultimately joint assessment of maximum wind speed, former and latter LAI values is going to demonstrate the integrated consequences.

3.1 Maximum Wind Speeds and Directions

Annual maximum wind speeds tended to spread extending from 61.2 km/h to 121.7 km/h along the last fifteen years (1998 to 2012) as indicated by the Figure 3b. The spreading can apparently be seen in Figure / Şekil 3a also on monthly basis.

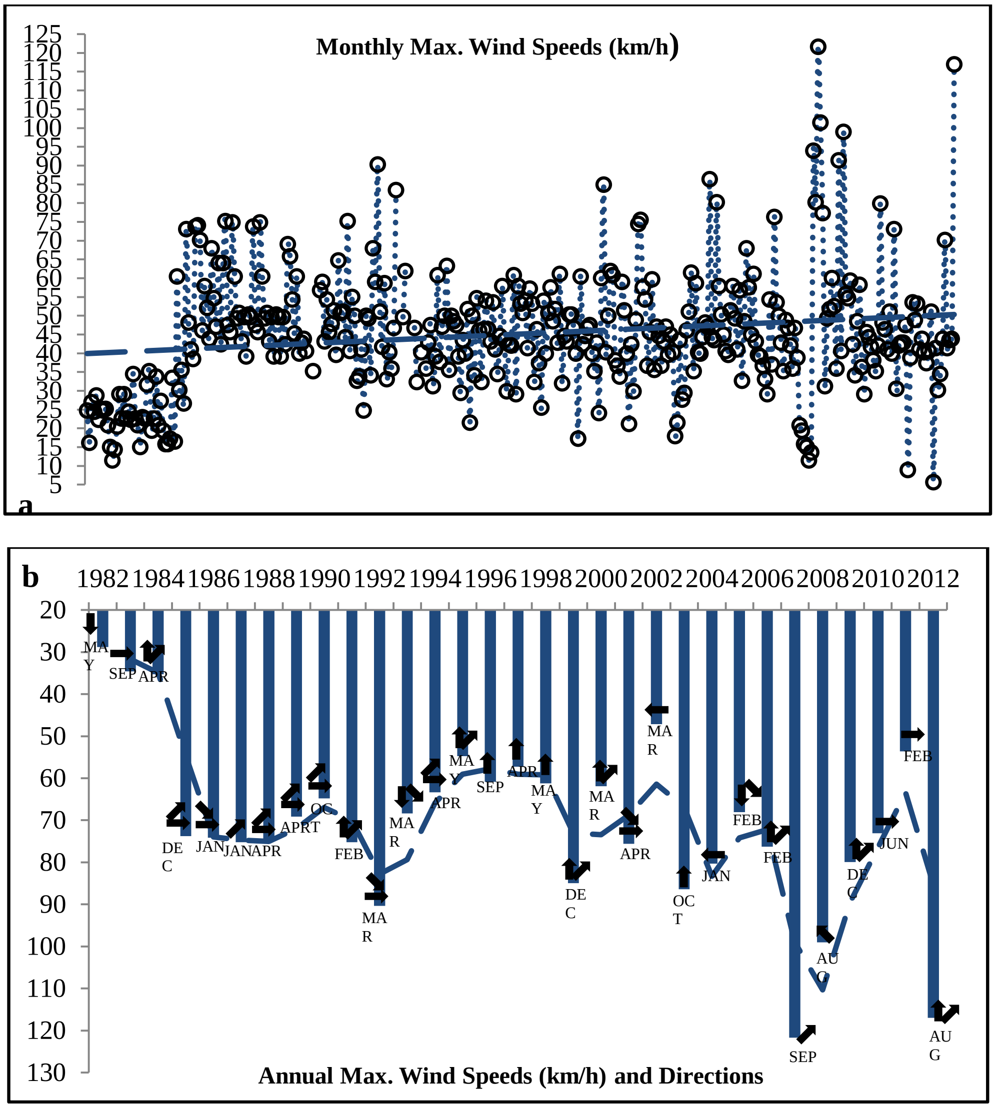

Figure 3. Monthly maximum wind speeds (a). Annual maximum wind speeds (km/h) and directions (b) between 1982 and 2012.
Şekil 3. 1982 ile 2012 yılları arasında aylık maksimum rüzgâr hızları (a). Yıllık maksimum rüzgâr hızları (km/saat) ve yönleri (b).

However, relatively more stable profile was exhibited throughout the thirteen years (1985 to 1997) when the maximum wind speeds ranged between 54.7 km/h and 75.2 km/h. On the other hand, the year 1992 is the only exception within that period with the maximum wind speed of 90.4 km/h. The first three years (1982 to 1984) were considerably calmer compared to the subsequent 28 years. Namely the maximum wind speeds were 28.8 km/h, 34.6 km/h and 35.3 km/h respectively within that short period. Even though the maximum wind speed of 2007 (121.7 km/h) exceeded the one of 2012 (117.0 km/h), we have no definite measured data reporting forest disturbance regarding the former period. The situation is valid for the other closer maximum wind speeds.

Dependent upon the number of the winds, although dominant wind direction is from western-northwestern and northern-northeastern directions (Figure / Şekil 1 and Figure / Şekil 2), particularly western-southwestern, southern-southwestern and southern winds constitute the ones with the maximum speeds. In addition, the western-northwestern and northern-northwestern winds are respectively the secondary and thirdly dominant winds from the point of their maximum speeds (Figure / Şekil 3b). According to both the annual and monthly basis, maximum wind speeds are associated primarily with the winter and spring months from December to May when both southern-southwestern and western-northwestern winds particularly prevail. On the other hand, August, September and October are the months when winds with maximum speeds blow from anywhere without particular direction.

Pre-and Post-Windstorm LAI Analysis

Comparison of the pre-windstorm and post-windstorm LAI revealed significant difference between the former and latter situations (Table 1, Figure 4). Namely, the mean decrease in the LAI was 24% both for the recreation and control sites. The mean LAI of the recreation site was slightly higher (0.8%) than the control site both before and after the severe windstorm. The highest LAI reached up to 3.18 before the severe windstorm in the control site whereas dropped down to 1.68 in the recreation site after the storm. On the other hand, the highest declines in the LAI were 32% and 30% for the recreation and control sites respectively. The lowest declines in the LAI were 17% and 18% respectively for the two points of recreation and control sites where defoliation happened in the form of solely leaf falls due to the vibration.

Table 1. Pre- (Aug. 1st, 2012) and post-windstorm (Sep. 1st, 2012) Leaf Area Index values of the recreation (R), control (C) points and their percentage of change together with some of the associated meteorological variables.
Tablo 1. Rekreasyon (R) ve kontrol (K) noktalarının fırtına öncesi (1 Ağustos 2012) ve sonrası (1 Eylül 2012) Yaprak Alan İndisi değerleri ve bu değerlerin değişim yüzdeleri ile ilgili meteorolojik göstergeler.

	Pre-Windstorm	**Post-Windstorm**	**±% Change**
LAI-R1	2.24	1.68	-25
LAI-R2	2.81	1.99	-29
LAI-R3	2.49	2.01	-19
LAI-R4	2.95	2.31	-22
LAI-R5	2.93	2.42	-17
LAI-R6	2.96	2.02	-32
Mean LAI-R	***2.73***	***2.07***	***-24***
LAI-C1	2.83	2.14	-24
LAI-C2	2.90	2.37	-18
LAI-C3	3.18	2.23	-30
Mean LAI-C	***2.97***	***2.25***	***-24***
Mean Temperature (°C)	24.46	20.78	-15
Max. Temperature (°C)	31.08	28.81	-7
Min. Temperature (°C)	18.98	13.77	-27
Mean Sunlight Duration (h)	8.56	9.51	+11
Mean Wind Speed (km/h)	1.50	1.52	+1.75
Total Precipitation (mm)	26	146	

According to the meteorological data consisting of ten days before (Aug. 2nd - Aug. 11th) and nineteen days after (Aug 13th – Aug 31st) the windstorm, it can be asserted that no marked extraordinary condition occurred before and after (Table 1). Namely, the maximum, minimum, and mean temperature and mean wind speed changes are around seasonal averages. However, the slight increase in the sunlight duration is not unexpected within that short time. The sharp, almost six fold increase in the precipitation is due to the severe southwestern windstorm. Nevertheless, the energy gained by the maximum wind speed of 117 km/h was sufficient to damage the trees leading to the 24% decline of LAI in the urban forest patch.

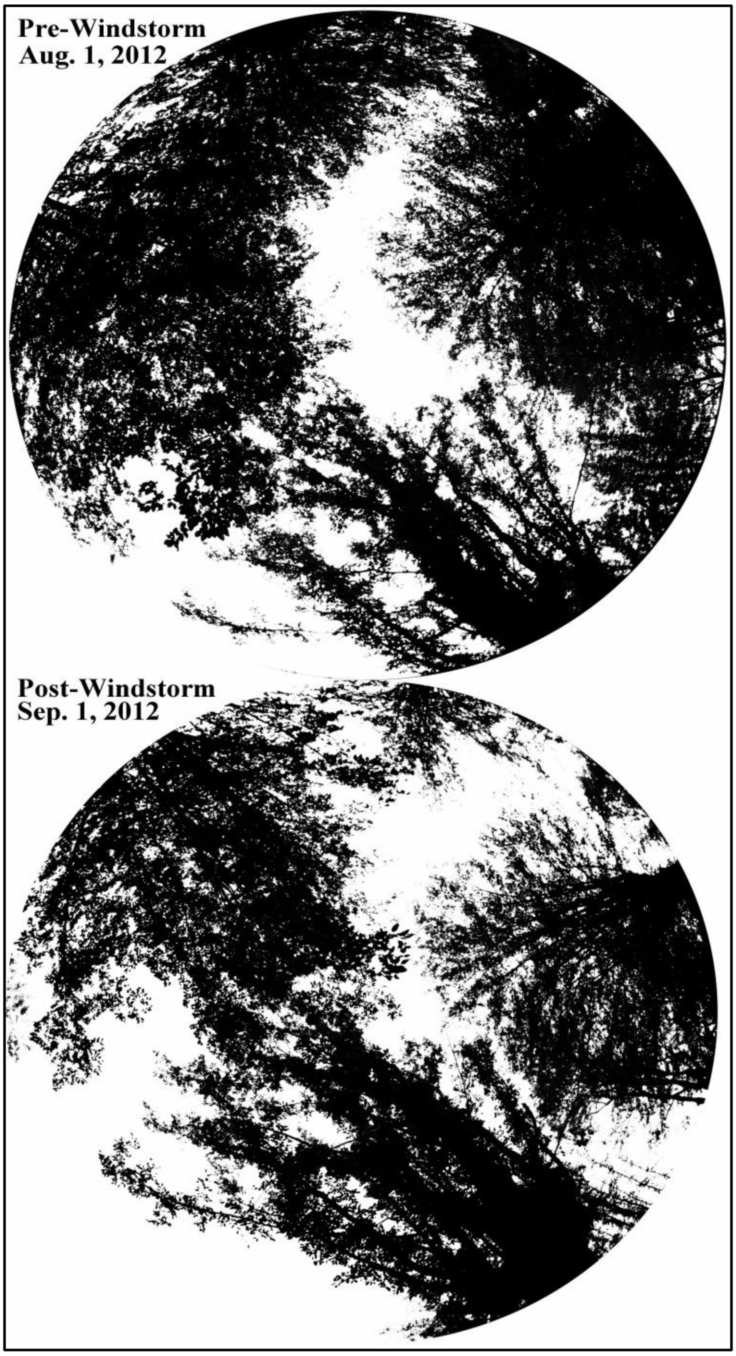

Figure 4. Sample hemispherical photos of the first photographing point (recreation) indicating the pre- (Aug. 1st, 2012) and post-windstorm (Sep. 1st, 2012).
Şekil 4. Birinci fotoğraf noktasının (rekreasyon) fırtına öncesi (1 Ağustos 2012) ve sonrasını (1 Eylül 2012) vurgulayan örnek yarıküre fotoğrafları.

4. DISCUSSION

The scattered pattern of annual and monthly maximum wind speeds particularly after the 1998 implies the sequences of urbanization where urban forest patches were replaced with buildings. Aerodynamically inflexible structure of the impermeable vertical surfaces favors diffuse winds in the urban environment (Oke, 1989) which result in concentrated flows with increased speeds (Marsh, 2010) that are more severe and even more destructive. However, forest canopies which tend to be resilient against winds (Lugo, 2008) contribute to the deceleration of the winds in the urban areas (Chen and Jim, 2008). On the other hand, beyond the role of the urban built and natural environment, dispersed maximum wind speeds within the last fifteen years may indicate an alert for climate change. IPCC (2012) suggested that fluctuating and accelerated maximum wind speeds are associated with climate change. In fact, the rising frequency of the wind-relevant extremes and their ecological consequences are referred to climate change phenomena (Hulme, 2005). Correspondingly, maximum wind speed trend has turned from severe breeze (1982 to 1984) to strong storms (1985 to 1997) and then to severe storms (1998 to 2012) in general. The severe storms of 2007 and 2012 have been the most extreme two southwesters within the period between 1982 and 2012 denoting the influence of southwesters on the regional climate and ecology.

From the point of meteorological variables, extremes were not suffered before and after the windstorm. However, the only exception is the amount of total precipitation (146 mm) following the windstorm (Table 1). In addition, about 65% (94 mm) of this total precipitation was poured immediately in subsequent two days (TSMS, 2013) which could be carried by the southwester. Southwester which is formed under the low pressure, is associated commonly with heavy rainfall (Türkeş, 2010). The effect of the season in the decrease of the LAI (natural defoliation) that mostly is influenced by the temperature (Bequet, 2011) was assumed to be minor compared to the instantaneous defoliation. Supporting the assumption, Öztürk (2015) observed that about 2°C decline along the August of 2012 had accounted for only 0.7% decrease in the LAI for the *Platanus orientalis* L. in the region. Consequently, almost all the 24% decrease in the LAI is judged to have been an inheritance of the severe windstorm. The impact of the soil compaction within the recreation site (Kara and Bolat, 2007) on the windthrow can be ignored since same percentage of LAI decrease (24%) was valid for the control site which has not been exposed to human trampling. The stem and branch breakages and uprooting occurred evenly within both recreation and control sites regardless of the tree age. Regeneration partially suffered the severe windstorm within the control site where human trampling was substituted by knockdown trees.

5. CONCLUSION

Windthrow breeds serious ecological consequences involving the impacts on urban forest landscapes particularly on their foliage, soil, litter, and regeneration characteristics (Lehvävirta, 2007). Moreover, windthrow pose considerable economical drawbacks not only for the urban built environment but also for the natural environment (Changnon, 2011). However, the overlooked social hazard of the windthrow is that impeding the sustainability of the urban forest patches which provide recreation areas for public. The shade supplied by the forest canopy in summer surpasses their numerous substantial contributions. Hence, any of the natural and anthropogenic pressures on their canopy quality should be overcome.

Although windthrow is a natural phenomenon and is hard to be completely prevented, precautions involving the mitigation of the wind speed and diverting the wind are to be taken. These can to some extent be achieved by spatially precise afforestation practices against wind directions. In addition, long term monitoring through remote sensing techniques which process satellite and ground-based images will assist the sustainability of the urban forests against natural and anthropogenic stresses. Further projects which entail ecological modeling attempts considering the climate change scenarios should definitely be supported to predict natural payoffs in response to the rapid urbanization.

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