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Original Article

Fragmentation effects on the structure of some urban forests in İstanbul

Parçalanmanın İstanbul'daki bazı kent ormanlarının yapısına etkileri

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ABSTRACT

Forest fragmentation is the separation or division of large forests into smaller units. Areas with non-forest lands significantly threaten the health, function, and value of the remaining forest. This study describes the effects of fragmentation on diversity of forest in the city of Istanbul. We obtained inventory data from local forest management and silvicultural plans (2002–2007). The data were used to determine the spatial variation in forest structure and biodiversity across six urban forest fragments in Istanbul, Turkey. We calculated a core set of patch- and class-level metrics in order to predict forest basal area within sample plots. We tested a number of regression models and employed the best-fitted model to extrapolate forest diversity across the urban forest fragments. Results indicate consistent relationship between spatial and silvicultural variables, suggesting the impact of fragmentation on the forest structure and biodiversity in Istanbul. Species richness of green spaces in urban areas was higher when compared to that of peri-urban areas. The location and the sizes of urban forests were associated with difference in societal expectations from these areas. As a consequence of the expectations, there was a change in forest structure in Istanbul. This study could be conducted for any other urban areas including large growing cities and megalopolis.

Keywords: Basal area, exotic-native species, patch-level metrics

ÖZ

Orman parçalanması, büyük ormanların daha küçük birimlere ayrılması veya bölünmesidir. Ormansızlaşan araziler, geri kalan ormanın sağlığını, işlevini ve değerini önemli ölçüde tehdit eder. Bu çalışma, İstanbul ilinde parçalanmanın orman çeşitliliği üzerindeki etkilerini tanımlamaktadır. Envanter verileri, yerel orman amenajman ve silvikültürel planlardan elde edildi (2002–2007). Veriler, İstanbul kentinin altı kent ormanı parçasının orman yapısındaki ve biyolojik çeşitlilikteki mekansal değişimini belirlemek için kullanılmıştır. Örnek alanlardaki orman göğüs yüzeyini tahmin etmek için temel bir parça ve sınıf düzeyi metrikleri kümesi hesapladık. Bir dizi regresyon modelini test ettik ve kent ormanı parçaları boyunca orman çeşitliliğini tahmin etmek için en uygun modeli kullandık. Sonuçlar mekânsal ve silvikültürel değişkenler arasında tutarlı bir ilişki olduğunu göstermektedir ve bu da parçalanmanın orman yapısı ve biyolojik çeşitlilik üzerindeki etkisini göstermektedir. Kent içindeki yeşil alanların tür zenginliği, kent kenarlarındakilere göre daha yüksek bulunmuştur. Kent ormanlarının konumu ve büyüklükleri, toplumun bu alanlardan beklentilerinin de farklılaşmasına neden olmuştur. Beklentilerin bir sonucu olarak, İstanbul'da orman yapısının değişmesini sağladı. Bu çalışma, büyümekte olan kentler ve büyükşehirler dahil olmak üzere diğer tüm kentler için gerçekleştirilebilir.

Anahtar Kelimeler: Göğüs yüzeyi, egzotik-yerli türler, parça düzeyi metrikler

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INTRODUCTION

Degradation of forest is the reduction in the capacity of a forest to produce ecosystem services. This reduction is a result of anthropogenic and environmental changes (FAO, 2002). The effects of degradation on forests are well-documented, with urbanization often being responsible for the loss and fragmentation of forest cover (Kerr and Deguise, 2004; Verburg et al., 1999; Wang et al., 2006). The growing demand for infrastructural development could significantly exert pressures on the available green and/or open spaces (Benedict and McMahon, 2006). Several studies have demonstrated the ecological role of green spaces in an urban setting. Forest areas and trees provide a wide range of ecosystem services and functions, including the provision of habitat, for a diversity of plant and animal species (Dearborn and Kark, 2010; Nowak and Dwyer, 2007). However, the diversity of species in urban areas is highly influenced by the structural features and spatial arrangement of green spaces (Blair, 2001; Kowarik, 1995; McIntyre, 2000). Small and isolated patches of forest in urban areas are more exposed to disturbance and edge effects when compared to larger and connected green spaces (Breuste et al., 2008; Qureshi et al., 2010). The concept behind forest in urban areas has many different definitions based on the forest and urban understanding of countries. Some countries accept a street tree as forest in urban areas, while others accept a certain size of woodland inside or near the cities. In Turkey, the concept behind forest in urban areas is defined as "forests that provide social functions such as health, sports, aesthetics, and cultural, among others, and also promote technical forestry activities and flora and fauna in the region inside or near metropolitan areas, provinces, and big districts".

Several studies have documented the edge effects on the structure of forest stands (Esseen and Renhorn, 1998; Matlack and Litvaitis, 1999; Saunders et al., 1991). Changes in composition species can be driven by factors such as microclimate conditions and/or dispersal of invasive species along edge locations (Medley et al., 1995; McKinney, 2002; Sukopp and Werner, 1982). Loss of habitat is the main reason for the loss of diversity of species (Pimm et al., 1995). In addition to edge effect, human activities have also contributed to the change in structure (Hitimana et al., 2004) and diversity of tree species (Cannon et al., 1998) of forests.

Forest stands, which are less common within and around cities, have become isolated areas. Forest stands often comprise invasive non-native plant species (McKinney, 2002; McKinney and Lockwood, 1999). However, other non-native species have also been enhanced in cities through local planting and proper management (pruning, fertilizer application and irrigation) (Henderson et al., 1998). In addition, new plant species serve as new sources of food for the sustenance of other species such as birds (Adams, 1994). As a result, in terms of biodiversity, urban areas are now richer than rural areas (Kellert, 1996; Klotz, 1990; McKinney, 2002; Qureshi et al., 2010; RCEP, 2007; Von der Lippe et al. 2005).

Studies on ecology of urban areas revealed a growing interest in the value and preservation of biodiversity (Qureshi and Breuste, 2010). Some studies have investigated the effects of fragmentation on the spatial distribution of woody species and forest structure (Echeverría et al., 2007; Metzger, 2000; Tabarelli et al., 1999). These studies revealed that habitat fragmentation affects the distribution of species, as well as, the forest structure (Kolb and Diekmann, 2005). Many studies have emphasized the changes that occur from the edge to interior of forest (Porter et al., 2001). There is dearth of information about the comparative analysis of forest stands throughout the landscape of a city.

Numerous methods and metrics have been developed for measuring the fragmentation of forest and its context (McGarigal and Marks, 1994, Mladenoff and DeZonia, 1997, Wickham and Norton, 1994). According to literature, landscape metrics can be located at the patch, class (patch type) and/or landscape level. Choosing a proper metrics that quantifies the landscape composition and configuration is the major challenge in this study. This is because each metric quantifies one aspect of landscape pattern and sometimes quantifies the same aspect partially or completely. Patch density (PD) and mean patch size metrics are good examples for redundant uses at the landscape level because they contain the same information. Therefore, it is important to choose the appropriate metrics suitable for its scale (patch, class, or landscape) (McGarigal and Marks, 1994). The main aim of this study is to understand the edge effects on the patches of Istanbul city.

In this study, we examined the effects of fragmentation on plant communities within selected urban forest areas in Istanbul. We obtained inventory data from local forest management and silvicultural plans (2002–2007) in order to determine the spatial variation in biodiversity of forest across six urban forest fragments near the canal that merged Black sea to Marmara sea (Bosphorus). Possible determinants of forest structure in the urban areas of Istanbul, such as locations of urban forests, stand size, and human influences of forest structure and species diversity, were investigated, and analyzed. By analyzing the effects of fragmentation on plant communities, this study aims to provide better insights on how to manage the urban forests of Istanbul toward providing various forest functions.

MATERIALS AND METHODS

Study Area

The city of Istanbul is located in north-west Turkey and stretches over two continents, Europe and Asia (Figure 1). Istanbul has approximately 15.5 million inhabitants, covering a surface area of 5400 km^2 (TUIK, 2020). Total forest area is around 245 thousand ha, which constitutes 44% of the total city area (OGM, 2020). Most of the forests in Istanbul are located along the Black Sea coast in the north axis of the city. The most common species

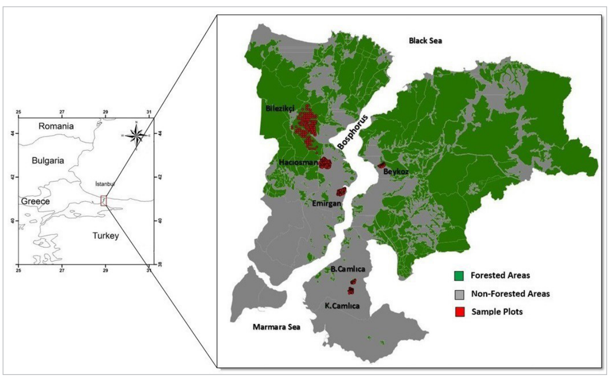

Figure 1. Land-use map showing the sub-municipalities and sample plots used for the study

include *Quercus sp., Pinus pinaster, Pinus nigra, Fagus orientalis, Pinus brutia, Castanea sativa, and Fraxinus spp.* (Asan et al., 2010). In addition, the urban forests in Istanbul include a large number of green spaces and small forest patches in the center of the city.

Forest areas were mainly selected on the basis of their location and size. Areas chosen for this study are categorized into two: small patches located at the Asia side of the Bosphorus, and large patches located at the Europe side. Also, the aforementioned large patches are located close to the north side of the city but far away from the downtown area.

Most of the forests in the urban areas are owned by Istanbul Metropolitan Municipality. Since the Istanbul's coastline has the highest level of urbanization (80%), we focused on the sub-municipalities adjacent to the Bosphorus and selected six urban forest areas (Bilezikçi, Hacıosman, Emirgan, Küçükçekmece, Büyükçekmece and Beykoz) for the study (Figure 1). Forest size ranged from 13 to 743 hectares, while altitude ranged from 0 to 250 meters above the sea level (average altitude=80 meters) (Table 1). Bilezikçi is owned by Istanbul University-Cerrahpaşa, located on the European side of the city. It is the largest (743 ha) among the study areas in terms of habitat. It constitutes a forest that mainly consists of coppice-originated stands, which was so named because it had been used as coppice land in the past (Asan et al., 2007).

"Hacıosman" was afforested in 1950 and constitutes a plantation mainly dominated by coniferous species (Asan et al., 2002), and is also located on the European side of the city. The other urban forests (Emirgan, Beykoz, Küçük Çamlıca, Büyük Çamlıca) were fragmented a long time ago, and are located within urban settlements and have historical features. The five study areas owned by the Municipality are isolated within the most urbanized settlement areas, attracting a great deal of public attention.

Field Sampling

We obtained inventory data from local management and silvicultural plans (2002–2007) in order to determine spatial variation in forest biodiversity across the six urban forest areas. Inventory data contains various measurement techniques for different kinds of plant composition. Field measurements were made in circular sample plots (Figure 2) and distributed in a systematic fashion. The sizes of the circular plots (200 m^2, 30 0m^2, 400 m^2 or 600 m^2) were determined based on stand density. We standardized the basal area and other parameters to hectare estimates for each sample plot. All trees with a diameter (DBH) ≥7 cm in the sample plots were measured, with their species, heights and health status (insect, fungi, dead tree, etc.) recorded. In total, we analyzed 398 circle plots containing 9991 trees. Furthermore, the distance from each plot to the forest stand edge was estimated using a geographical positioning system. The forest cover map that we used in this study is digitized by satellite images into two main areas, that is, forested and non-forested areas.

Statistical Analysis

The effect of fragmentation on plant communities was modeled by analyzing the differences in structure of urban forests

Table 1. Main properties of urban forests chosen for the study

Urban Forests	Location	Area (ha)	Owner	Main species	Features
Büyük Çamlıca	ASIA 29° 03' 58" - 29° 04' 17" E. L 41° 01' 30" - 41° 01' 47" N.L.	13	İstanbul Metropolitan Municipality	*Pinus pinea,* *Pinus nigra,* *Platanus sp.*	Fragmented long time ago, contained within urban settlements, have historical features.
Küçük Çamlıca	29° 03' 44" - 29° 04' 10" E. L. 41° 00' 49" - 41° 01' 21" N.L.	25	"	*Quercus sp.,* *pinus pinea,* *Cupressus sp.,* *Tilia sp.*	"
Beykoz	29° 05' 33" - 29° 06' 30" E. L 41° 07' 54" - 41° 08' 16" N.L.	28	"	*Quercus sp.,* *Platanus sp.,* *Tilia sp.*	"
Emirgan	EUROPE 29° 02' 53" - 29° 03' 31" E. L 41° 06' 23" - 41° 06' 50" N.L.	43	"	*Fraxinus sp.,* *Tilia sp.* *Quercus sp.* *Aesculus sp.* *Pinus pinea,* *Cedrus sp.*	"
Hacıosman	29° 01' 25" - 29° 02' 53" E. L 41° 07' 23" - 41° 08' 29" N.L.	122	"	*Pinus pinea,* *pinus pinaster,* *Pinus nigra*	Afforested in 1950 with plantations
Bilezikçi	28° 59' 17" - 29° 32' 25" E. L 41° 09' 15" - 41° 11' 01" N.L.	743	İstanbul University - Cerrahpasa	*Quercus sp.,* *Castanea sp.,* *Carpinus sp.* *Tilia sp.,* *Laurus nobilis*	It was used as a coppice land.

on both sides of the Bosphorus. Fragstats was used to analyze the plot data and landscape metrics. Patch-level metrics, termed "class-level metrics" in fragstats, were calculated using neighborhood radii of 500 m. Six fragmentation metrics were used to determine the edge-effects on forest patches of Istanbul city (Table 2).

Edge effect was determined by observing the change in the basal area of plant communities from edges to the interior of forests. The analyses of metrics was performed by scanning a radius of 500 meters around each sample plot. In other words, the relationship between each metric and basal area were determined for every sample plot by analyzing the entire physical structure along the radius of 500 meters on a map of forest cover (Figure 2). The size of a radius is determined based on the size of the patches, and the analysis is done in this circle. The examination was conducted over the "forest cover data" (cell size=25) converted into raster using Fragstats v.3.3 (McGarigal and Marks, 1995).

The correlation between each fragmentation metric and the basal area was determined using R- statistics software. Data were grouped into two (small and large patches). All analysis was conducted for each group, separately. Metrics that were correlated with basal area were used for the development of a model that best explains the relationship between them. In this regard, a combination of two, three, or more metrics were examined.

Models were screened according to AIC (Akaike information criterion) value to determine the best supported models. In this regard, Akaike weight was calculated and used to determine the probability that any given model was the "best-fitted" of the candidate set (Burnham and Anderson, 2002). The change in the basal area while going from the forest edge to the inside was modeled with metrics in order to determine the edge effect. Three models that had the lowest AIC value were obtained by separate assessments of the urban forests on each side of the Bosphorus.

After determining the changes in basal area for each side of Bosphorus, we have investigated the changes in the number of trees and volume for each side so as to have a better understanding of the main factor responsible for the changes in basal area (Figure 2, 3).

In addition, the number of native and exotic species on both sides of the Bosphorus was determined using sample plot measurements. This was done to determine whether the size and location of the urban forests influences the number of exotic species. All values were obtained from the measurements made on the basis of forest stands (DBH) ≥7 cm), excluding groundcover plants.

Figure 2. Distribution of sample plots (Hacıosman) and form of analysis for each plot

Table 2. Fragmentation metrics that used in this study

Type of measure	Metrics	Description	Unit	Range
Patch-level	DIST.EDGE	Distance to the nearest forest edge	km	DIST.EDGE ≥ 0
	PD.500	Number of forest patches per unit area	km^2	PD.500≥0
	ED.500	Total length of forest edges per unit of area	km	ED.500>0
Metrics	PLAND.500	Percentage of forest landscape	%	PLAND.500 ≥ 0
	MSI.500	Mean shape index of forest patches	km	MSI.500≥1
	AI.500	Aggregation index	%	AI.500≥0

RESULTS AND DISCUSSION

The results are presented separately for both sides of the Bosphorus (Table 3). PD, edge density and mean shape index indicate that small patches of Asian side are more fragmented than those of large European patches.

Basal area increased from stand edge to interior in small patches but decreased in large patches (Figure 3).

Our regression models indicate that the metrics "Percentage of forest landscape (PLAND_500)", "Edge Distance (DIST_EDGE)" and Edge Density (ED_500) had significant effects on basal area in the small and large patches of İstanbul chosen for this study (Table 4). Correlation matrix of fragmentation measures and Coefficients of best models for each side (Europe–Asia) are given in Appendix 1, respectively.

In the small patches, tree volumes increased while, however, there was a slight decrease in number of trees from edge to the

Table 3. Summary characteristics of metrics that were used for the patches

	Small Patches (Asia)			Large Patches (Europe)		
Metrics	B.Çamlıca	Beykoz	K.Çamlıca	Bilezikçi	Emirgan	Hacıosman
Dist_Edge	36.15	187.96	42.81	294.83	105.41	150.52
ED_500	68.82	44.01	73.72	21.12	28.86	35.23
PD_500	1.62	2.34	2.33	1.6	1.26	2.21
PLAND_500	17.24	77.42	27.21	91.8	40.71	64.97
AI_500	80.09	96.27	86.94	98.21	98.26	97.35
MSI_500	3.51	1.76	2.33	1.47	1.36	1.48

Table 4. Best models predicting the effect of landscape metrics on the basal area of stands located within European (large patches) and Asian (small patches) sides of Istanbul. The combination of landscape metrics with the lowest AIC value is presented at the top. The change in AIC between the model on top and the second and third best models were also stated

Data	Model	AIC	ΔAIC	L(gi|x)	wi
Large Patches	PLAND_500+ED_500+AI_500+DIST_EDGE+PD_500	359.09	1.710	0.425	0.223
	PLAND_500+ED_500+AI_500	358.84	1.460	0.482	0.253
	PLAND_500+ED_500+AI_500+DIST_EDGE	357.38	0.000	1.000	0.524
Data	Model	AIC	ΔAIC	L(gi|x)	wi
Small patches	ED_500+DIST_EDGE+PLAND_500+MSI_501+AI_500+PD_500	167.56	1.540	0.463	0.196
	ED_500+DIST_EDGE+PLAND_500+MSI_500+AI_500	166.22	0.200	0.905	0.382
	ED_500+DIST_EDGE+PLAND_500+MSI_500+PD_500	166.02	0.000	1.000	0.422

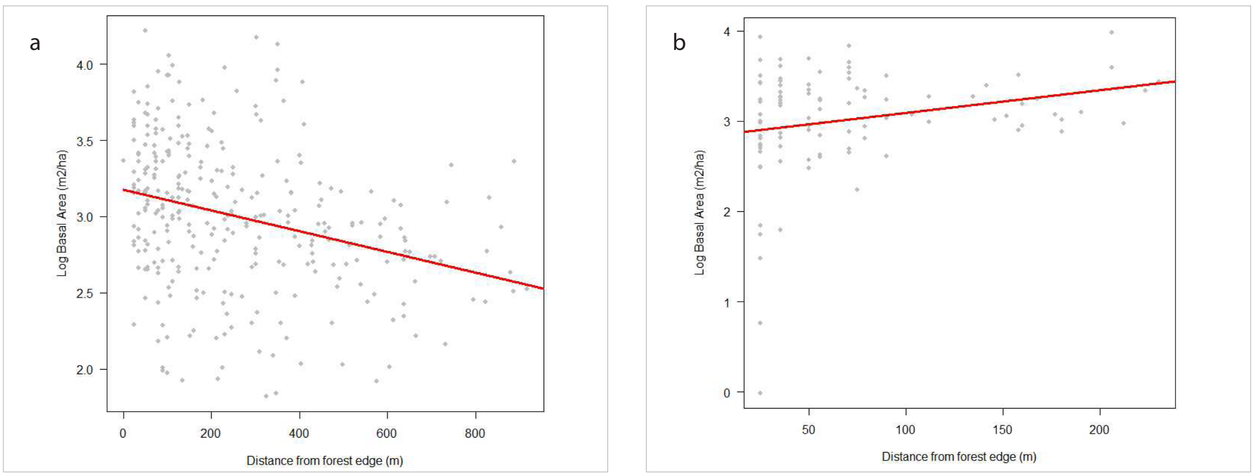

Figure 3. a, b. Relationship between the basal area and edge distance in both sides of the Bosphorus. a) Large patches (r^2=0.21), b) Small patches (r^2=0.21).

interior of the forest (Figure 4). In the large patches, the number of trees is increased, however, the tree volume decreased along the edge to the interior gradient (Figure 5).

A high species richness for both native and exotic species were found within the forests (Table 5). It was seen from the inventory results that Bilezikçi and Hacıosman forests, which are larger in size and farther away in location from the downtown area, contain less exotic species.

Changes in the Forest Structure

The first objective of this study is to understand the effect of fragmentation on the forest structure of selected forest patches. This effect was determined by the changes in the basal area of patches from the edge to interior of forests. The analysis considered two groups, which are the small and large patches on Asia and Europe sides of the Bosphorus, respectively. In the present study, there was increase in the number of trees while a decrease in the volume of trees from the edge to interior forest

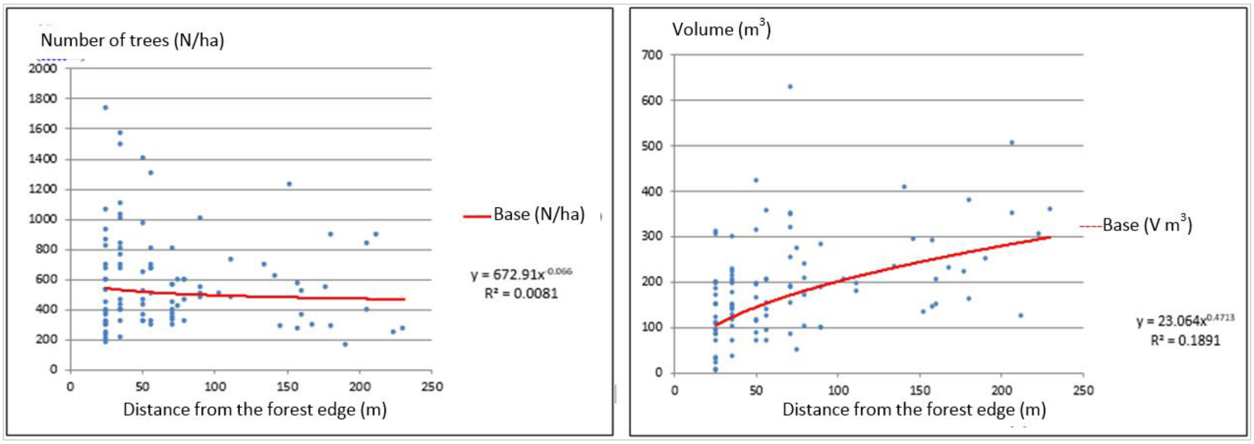

Figure 4. Changes in number of trees/volume from edge to interior forest (Small patches)

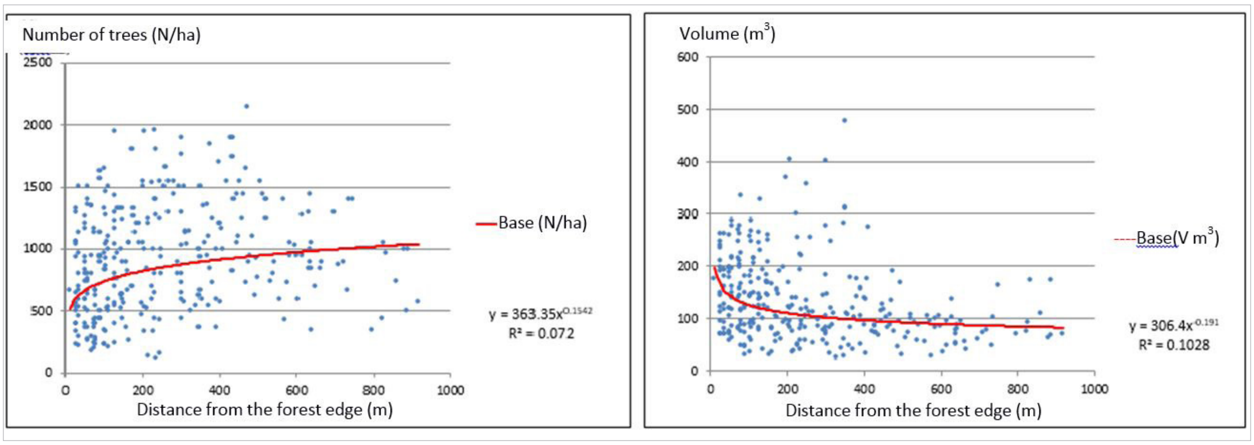

Figure 5. Changes in number of trees/volume from edge to interior forest (Large patches)

Table 5. The number of exotic and native plants*

Small				Large			
		Species richness				Species richness	
Patch name	Area (ha)	Exotic	Native	Patch name	Area (ha)	Exotic	Native
Beykoz	28	27	31	Bilezikçi	743	4	16
K.Çamlıca	25	7	25	Hacıosman	122	4	38
B.Çamlıca	13	7	27	Emirgan	43	30	62
Total	66			Total	908		

*Information about the species with (DBH)≥7 cm in the sample plots is shown. Groundcover plants are excluded.

of the large patches (Figure 1 and 3). In the small patches, the number of trees did not change significantly, however, the volume of trees increased from the edge to interior forest. These findings indicative that small patch structures are different from large patch structures. The results on the large patches, in terms of basal area and other related parameters (number and volume of trees), are similar to those of previously conducted research (Harper et al., 2005; Linera and Williams, 1990; Oliveira et al., 2004). However, these reports considered forests that are located around and outside cities. The edge effects (for large patches) observed in this study is comparable to those of the aforementioned studies.

Effects on Species Diversity

Diversity of species was analyzed for each patch in the context of exotic and native species. The largest patches (Bilezikçi and Hacıosman) had less tree richness compared to other patches (Table 5). Particularly, in the context of exotic species, these large patches have only four different exotic species for each of them. Emirgan, the third largest patch, had the highest species richness among the six forest patches. The other three small patches were significantly diverse in relation to their sizes. Also, the native species were dominant while the forest area increased.

Suggestively, the two main reasons for the observed structural differences between the two groups of patches are their distance from an urban center and their different management regimes. Based on local expert knowledge, we observed that the level of intervention by the community is dependent on how far the green patches are located from the urban areas. In order words, the level of intervention is high when the location of the green patch is close to urban areas. Suggestively, the reason for this may be that the patches closer to the city center tend to be smaller and easier to manage. Therefore, there is a high demand on management due to daily use of these areas by the surrounding community (in terms of visits, picnics, etc.) and expectations of the community (in terms of aesthetics and valuing diversity of species). Patches farther from the city tend to be larger and require less interventions. This is because the community mainly uses these large areas as wilderness and/or for recreation, and because these areas are being protected by conservation regulations. This study did not make sufficient rigorous observations to draw any conclusions on the theory about the effects of distance from urban center and differences in management regimes. Therefore, future research in this area would be required to clarify the relationship between these potential driving factors and phenomenon observed in this city about the physical forest structure and diversity of species. There are existing scientific observations supporting some of the local expert knowledge cited in the above considerations. For instance, as reported by in Asan et al. (2007), Bilezikçi urban forest (considered a large patch in this study) provides habitat for large animals (roe deer, jackal, etc.) and about 146 bird species. Bilezikçi and Hacıosman patches (the largest in this study) constitute a bridge between the city and the forests that are mainly located at the north of the city. More also, further research is needed to clarify the influence of the factors potentially driving the physical forest structure and diversity of species in these patches.

Owing to the fact that socio-cultural requirements are prioritized in urban life, urban forests are managed in a different way than traditional forests. Structure and composition of forests has changed overtime as many forests have shrunk into patches adjacent to a nearby city or isolated patches within a city due to fragmentation caused by urbanization. Creation of edges is one of the major factors that changes forest structure. Understanding the interaction between urban forests and different man-made structures (roads, settlements, etc.), as well as forest usage, is important since the alteration of forest structure affects the forest benefits provided to the society. In this study, the effects of urbanization on forest structure were investigated through the size, location, and physical structure of forests in urban and peri-urban areas of Istanbul. This study revealed that the location and size of forest patches correlates with the differences in the edge effect on physical forest structure, and with differences in the species richness. In comparison of the larger and smaller patches, larger patches farther from urban areas tend to decrease in basal area from forest edge to interior (that is, increasing in stand density, and decreasing in volume) and, overall, have more native species. On the other hand, smaller patches closer to urban areas tend to increase in basal area from forest edge to interior (that is, stand density remaining consistent, and increasing in volume) and, overall, have more exotic species and greater diversity of species. Suggestively, the causes for these differences is suspected to be the management and use regimes for each group of forest patches. Therefore, further research focusing on those patterns may be required to identify clearer cause-and-effect relationships for the observed differences in forest structure and species diversity in this study.

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Correlations

		DIST_EDGE	PLAND_500	ED_500	PD_500	ENN_500
DIST_EDGE	Pearson Correlation	1	,675**	-,736**	-,252**	-,248**
	Sig. (2-tailed)		,000	,000	,000	,000
	N	300	300	300	300	300
PLAND_500	Pearson Correlation	,675**	1	-,488**	-,160**	-,320**
	Sig. (2-tailed)	,000		,000	,005	,000
	N	300	300	300	300	300
ED_500	Pearson Correlation	-,736**	-,488**	1	,511**	,201**
	Sig. (2-tailed)	,000	,000		,000	,000
	N	300	300	300	300	300
PD_500	Pearson Correlation	-,252**	-,160**	,511**	1	,480**
	Sig. (2-tailed)	,000	,005	,000		,000
	N	300	300	300	300	300
ENN_500	Pearson Correlation	-,248**	-,320**	,201**	,480**	1
	Sig. (2-tailed)	,000	,000	,000	,000	
	N	300	300	300	300	300
MSI_500	Pearson Correlation	-,524**	-,072	,684**	,071	-,039
	Sig. (2-tailed)	,000	,216	,000	,220	,500
	N	300	300	300	300	300
AI_500	Pearson Correlation	,598**	,354**	-,874**	-,637**	-,283**
	Sig. (2-tailed)	,000	,000	,000	,000	,000
	N	300	300	300	300	300

Correlations

		MSI_500	AI_500
DIST_EDGE	Pearson Correlation	-,524**	,598**
	Sig. (2-tailed)	,000	,000
	N	300	300
PLAND_500	Pearson Correlation	-,072	,354**
	Sig. (2-tailed)	,216	,000
	N	300	300
ED_500	Pearson Correlation	,684**	-,874**
	Sig. (2-tailed)	,000	,000
	N	300	300
PD_500	Pearson Correlation	,071	-,637**
	Sig. (2-tailed)	,220	,000
	N	300	300
ENN_500	Pearson Correlation	-,039	-,283**
	Sig. (2-tailed)	,500	,000
	N	300	300
MSI_500	Pearson Correlation	1	-,714**
	Sig. (2-tailed)		,000
	N	300	300
AI_500	Pearson Correlation	-,714**	1
	Sig. (2-tailed)	,000	
	N	300	300

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

		DIST_EDGE	PLAND_500	ED_500	PD_500	ENN_500
DIST_EDGE	Pearson Correlation	1	,756**	-,466**	-,032	-,108
	Sig. (2-tailed)		,000	,000	,758	,291
	N	98	98	98	98	98
PLAND_500	Pearson Correlation	,756**	1	-,659**	,008	-,113
	Sig. (2-tailed)	,000		,000	,938	,268
	N	98	98	98	98	98
ED_500	Pearson Correlation	-,466**	-,659**	1	,315**	,250*
	Sig. (2-tailed)	,000	,000		,002	,013
	N	98	98	98	98	98
PD_500	Pearson Correlation	-,032	,008	,315**	1	,647**
	Sig. (2-tailed)	,758	,938	,002		,000
	N	98	98	98	98	98
ENN_500	Pearson Correlation	-,108	-,113	,250*	,647**	1
	Sig. (2-tailed)	,291	,268	,013	,000	
	N	98	98	98	98	98
MSI_500	Pearson Correlation	-,451**	-,635**	,234*	-,581**	-,398**
	Sig. (2-tailed)	,000	,000	,020	,000	,000
	N	98	98	98	98	98
AI_500	Pearson Correlation	,674**	,911**	-,704**	-,143	-,203*
	Sig. (2-tailed)	,000	,000	,000	,161	,045
	N	98	98	98	98	98

Correlations

		MSI_500	AI_500
DIST_EDGE	Pearson Correlation	-,451**	,674**
	Sig. (2-tailed)	,000	,000
	N	98	98
PLAND_500	Pearson Correlation	-,635**	,911**
	Sig. (2-tailed)	,000	,000
	N	98	98
ED_500	Pearson Correlation	,234*	-,704**
	Sig. (2-tailed)	,020	,000
	N	98	98
PD_500	Pearson Correlation	-,581**	-,143
	Sig. (2-tailed)	,000	,161
	N	98	98
ENN_500	Pearson Correlation	-,398**	-,203*
	Sig. (2-tailed)	,000	,045
	N	98	98
MSI_500	Pearson Correlation	1	-,657**
	Sig. (2-tailed)		,000
	N	98	98
AI_500	Pearson Correlation	-,657**	1
	Sig. (2-tailed)	,000	
	N	98	98

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix 1. Correlation matrix of fragmentation measures (correlation coefficient=pearson)