Int. J. Environ. Sci. Technol. (2015) 12:3971–3980
DOI 10.1007/s13762-015-0826-x

ORIGINAL PAPER

# Assessment of landscape silhouette value in urban forests based on structural diversity indices

**U. Y. Ozkan[1] · I. Ozdemir[2]**

Received: 9 January 2015 / Revised: 24 March 2015 / Accepted: 25 April 2015 / Published online: 5 May 2015


**Abstract** Urban forests form an important component of the urban environment. They make a significant contribution to landscape silhouettes due to species diversity and the differences observed within forest communities such as tree composition, size and form. Visual effects such as these are referred as aesthetic value. Therein, quantitative assessments of targeted forest structures that will optimize aesthetic values are vital during urban forest planning. However, the silhouette effect, which is an important component of aesthetic value, has not been extensively studied to date. This study aims to reveal the relationship between forest structure, the visual quality of tree composition and the different forms and sizes that create the silhouette effect. To this end, virtual landscapes of different structures were created using computer-assisted images. The forest structure was characterized by a *Form Mingling Index* (*FMI*) and *Height Dominance Index* (*HDI*). A Pearson correlation was applied in order to find the relationship between the landscape silhouette values through a perceptual test as well as the *FMI* and *HDI*. The results of the analyses showed that there was a strong positive relationship between the *FMI* and *HDI* ($r = 0.78$, $r = 0.75$, $P < 0.01$, respectively) and landscape silhouette values. The combined effect of $FMI + HDI$ was found to have the highest relationship with landscape silhouette values ($r = 0.80$, $P < 0.01$). In conclusion, *FMI* and *HDI* offer a rapid, cost-effective method which can be used by managers to assess the silhouette value of an urban forest landscape.

**Keywords** Urban forestry · *Form Mingling Index* · *Height Dominance Index* · Silhouette value

## Introduction

Urban development and infrastructure result in the destruction of trees and forests that form an important component of urban environments (Misgav 2000). This in turn leads to a negative impact on the health and quality of life for city dwellers, as well as the aesthetic quality of the urban landscape (Hartig 1993). Therein, urban forests are becoming increasingly important features across the landscape. Urban forests can take many forms, such as tree stands in parks, vegetation within cityscapes, forest remnants as well as the establishment of green belts through afforestation (Mansfield et al. 2005). They provide a wide variety of environmental amenities such as shade, improved aesthetic quality, reduced soil erosion and traffic noise as well as improvement in air quality, storing carbon and decreasing stress in urban dwellers (Ode and Fry 2002; Voeks and Rahmatin 2004; Mansfield et al. 2005; Anyanwu and Kanu 2006; Sander et al. 2010). Particularly, in highly populated industrialized cities, ecosystem functions that support health, aesthetics, recreation and carbon storing are significant benefit to urban dwellers (Bell et al. 2005; Konijnendijk et al. 2006; Liao et al. 2013). Although these benefits are well known, they have not been adequately taken into account for urban forest planning (Tyrväinen et al. 2005a).

Urban forests provide variation across the landscape with each vegetation community having its own distinct

✉ U. Y. Ozkan
uozkan@istanbul.edu.tr

1 Department of Forest Management, Faculty of Forestry, Istanbul University, 34473 Istanbul, Turkey

2 Faculty of Forestry, Wildlife and Ecology Management, Süleyman Demirel University, 32260 Çünür, Isparta, Turkey

colour, form, texture and density. These variations add an aesthetic quality to the urban landscape (Dwyer et al. 1992; Tyrväinen et al. 2005a). Aesthetic quality is defined as a value judgment based on the appearance of a landscape and a person's emotional response to it (Daniel 2001). Thus, aesthetic value is of significance when evaluating the quality of urban forests and plays an increasingly important role in the planning of urban forests (Konijnendijk et al. 2006; Tyrväinen et al. 2006, Zhang et al. 2014). However, it is challenging to make an objective assessment regarding aesthetic quality and integrate it into management plans. This is because, the aesthetic quality and beauty of a landscape is subjective, it can and does, have an effect on peoples' emotional states and therefore gain a value according to a person's appreciation. Hence, aesthetic value is linked with a number of factors such as a person's level of education, previous experiences with natural landscapes, age and sex (Tyrväinen et al. 2005b; Golivets 2011).

Although the perception of aesthetic quality varies from one person to another, it is acknowledged that large groups of people share similar perceptions due to common cultural and personal experiences (Palmer and Hoffman 2001). In addition, it is possible to quantify aesthetic quality via landscape attributes which are known to have an influence on emotional response. The content and spatial arrangement of these attributes can be used to determine the aesthetic quality of urban forests (Arriaza et al. 2004; Tveit et al. 2006). It has been acknowledged that there is a strong relationship between plant cover attributes and aesthetic quality (Lohr and Pearson-Mims 2006). The diversity of plant cover is regarded as the key factor when evaluating a site for aesthetic quality; yet, a single tree can make a significant contribution to the aesthetic quality at any given location (Tyrväinen et al. 2005). Trees are therefore the most important elements of plant cover that define the aesthetic quality of urban areas (Dwyer et al. 1992). It has been shown that people do not react to all plants in the natural environment in the same manner, but they do react more positively to trees than to any other plant type (Lohr and Pearson-Mims 2006). The physical properties and symbolic value of a tree determine its attractiveness. Therein, trees that possess distinctive physical properties with respect to colour, size and form are important landscape elements for urban environments (Summit and Sommer 1999).

In order to determine the aesthetic value of urban trees and forests, there are two main approaches that of expert and perception-based values. However, the perception-based approach has been used more often to assess the aesthetic quality of landscapes (Daniel 2001). Previous studies have usually focused on the assessment of visual landscape choices on the basis of photographs, computer-assisted graphics and questionnaires. These types of assessment explored the relationships between aesthetic quality and landscape characteristics based on human preferences (Misgav 2000; Golivets 2011; Arriaza et al. 2004; Akbar et al. 2003; Bulut and Yilmaz 2008; Ode et al. 2009). There are, however, some shortcomings that need to be acknowledged when evaluating a site for its aesthetic quality. The most important ones are subjectivity and the lack of standardization in methodology. Therefore, in order to measure the aesthetic value of a forest, the methods chosen for the assessment need to follow an objective process (Dramstad et al. 2006; Panagopoulos 2009).

Aesthetic quality was the principle management decision in the last two planning periods of İstanbul, where the urban forests play an important role in the urban silhouette (Asan et al. 2013). Two components that form the aesthetic value are taken into account in planning the urban forests of İstanbul: (1) silhouette value and (2) mosaic value. *Silhouette value* is defined as the eye-pleasing formation on the horizon created by tree crowns located on the main ridges surrounding urban areas (Fig. 1a). The range of colours created by the tree stands on the slopes (especially during spring and fall) is referred to as *mosaic value* (Fig. 1b). Their common effect determines the aesthetic value of a forest landscape (Asan 2013).

During the planning stage of İstanbul urban forests, 30-m-wide strips on the hills and ridges, when viewed from different points of the main transportation lines and settlement areas, were classified as areas with silhouette value. In these areas, some silviculture treatments have been utilized to maintain species diversity as well as a varying range between tree age and growth form. Furthermore, it is proposed that an approximate tree density be preserved in order to allow for the visibility of tree crowns. However, the silviculture treatments projected to increase silhouette value are determined in a subjective way. As a result, the target forest structure should be determined based on the quantitative indicators in order to the silvicultural treatments aimed at improving the silhouette effect can be identified more accurately. This study therefore aims to improve upon previous methodologies by effectively quantifying the variables that account for enhanced *silhouette values* and thus increasing the aesthetic appreciation of urban areas. The study was performed between April 2014 and December 2014.

There have been relatively few published studies undertaken to determine the visual choice of different tree forms that constitute the main element of the green texture, within highly urbanized regions. For example, Summit and Sommer (1999) assessed different forms of trees with differing sizes and shapes and reported a significant difference between different forms of trees and their perceived attractiveness. A similar study conducted by Müderrisoglu et al. (2006) reported a significant difference


**Fig. 1** Components of a landscape's aesthetic value (**a** silhouette effect, **b** mosaic effect)

due to the influence of tree forms on visual choice. On the other hand, there is not any extensive study on the silhouette effect, which is an important component of aesthetic value. Nonetheless, for sustainable urban forest management, there is a growing need for more comprehensive studies that aim to assess the impact of tree composition on people in urban environments. Therefore, the hypothesis for this study is to establish whether there is a relationship between the silhouette effect (visual quality value of tree compositions in various form and sizes) and vegetation structure. Therein, this study will contribute to the understanding of which forest structures need to be targeted, in order to optimize the silhouette value in urban forests.

## Materials and methods

In order to initiate an understanding of how urban forest areas are reserved for their silhouette value, an investigation into the structure of the current urban forest management plans of İstanbul was undertaken. All trees were identified to species level and subsequently photographed. As a result of this assessment, six different tree forms round, columnar, pyramidal, conical, oval and irregular-shaped were identified (Fig. 2). Due to the absence of an adequate amount of landscapes within İstanbul that could represent different vegetation compositions, landscape simulations were undertaken. This approach standardizes the landscapes and eliminates factors that are not consistent with tree form and size. Computer-assisted visualizations also have certain advantages, in that they enable the creation of different landscapes with the added ability to diversify their contents under different scenarios. Previous studies have found a strong correlation between spot assessments and assessment of computer-generated images (Daniel and Meitner 2001; Bishop and Rohrmann 2003; Ode et al. 2009).

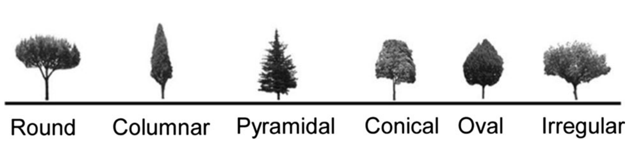


**Fig. 2** Tree forms used in the study

### Perceptual testing

The perceptual approach (i.e. the interaction between people and the landscape) is the most common approach used in studies to determine aesthetic quality of urban forests (Qin et al. 2011). In perceptual testing, the preferences of participants are tested through verbal questioning or visual presentations. For testing through visual presentations, landscape scenes are presented to groups that are asked to assess the aesthetic quality of the landscape, based on the images presented (Hulliv and Revell 1989).

For this study, perceptual testing in the form of visual presentations was used. Virtual landscapes with different vegetation compositions were created in different forms, which were then presented to the study group. Tree colours are known to cause differences in perception (Müderrisoglu et al. 2006); therefore, landscapes were prepared without colour. Forty artificial landscapes were presented to 99 volunteering students from within the Faculty of Forestry at İstanbul University. Before the questionnaire was conducted, the participants were informed about the importance of aesthetic function and silhouette effect as a part of the aesthetic function in planning forests. Participants were also informed that the natural beauty perception of people is important in determining the silhouette effect (sensu Clay and Daniel 2000). Participants were then asked to rank the silhouette effect of areas by using a 10-point scoring system (one very little value and ten very high value). Therein, each slide was shown for 10 s, as previous studies have found that the visibility time used for each slide has no significant effect on people's preferences (Herzog 1984; Tveit 2009).

However, one potential problem related to the landscape evaluation scale is thought to be the endpoint within the scoring system (Meitner 2004). This was explained as a lack of insight from participants of the evaluation process, where if the participant assigned the highest score to a scene previously shown, they could only assign the same score to a later similar scene, which they thought was more aesthetically pleasing. This problem could be partially overcome through a preliminary demonstration of sample images to participants. In this way, participants were able to have a preconceived perception on how they would score landscape scenes within the range of the scale used (Meitner 2004; Clay and Daniel 2000).

### Calculation of Form Diversity and Height Dominance indices

Structural diversity has been found to elicit an emotional response when viewing landscapes (de Val et al. 2006). Many indices have been developed to assess structural diversity (Shannon and Weaver 1949; Simpson 1949; Clark and Evans 1954; Holdridge 1967; Gadow et al. 1998; Aguirre et al. 2003; Hui et al. 1998; Ozdemir and Karnieli 2011). However, a neighbour-based index will more accurately reflect the landscape effect of neighbouring trees within the immediate vicinity of a reference point (tree). Therefore, the *Species Mingling Index* and *DBH (diameter at breast height) Dominance Index* that are calculated on the basis of neighbourhood were used in the study. The basic principle of these indices is that they rely on four neighbour trees that are the closest to the reference tree. In this study, some modifications were made in calculating these indices. First, the neighbour trees were agreed to be the four closest trees to the reference tree along a strip (Fig. 3). Secondly, form rather than species was used as the basis for classification and the *Species Mingling Index* was replaced by the *Form Mingling Index* (*FMI*). Likewise, instead of *DBH*, the heights of trees were used for classification; thus, *DBH Dominance Index* was replaced by the *Tree Height Dominance Index* (*HDI*). The index values of trees in the strip along the crest line of a ridge were calculated by means of the following formulas (Eqs. 1 and 2) (Gadow et al. 1998; Aguirre et al. 2003; Hui et al. 1998). The mean value of all trees was then calculated to find the total diversity value of each landscape.

$$FMI_i = \frac{1}{4}\sum_{J=1}^{4} V_{ij} \quad 0 \le FMI_i \le 1 \tag{1}$$

$$HDI_i = \frac{1}{4}\sum_{J=1}^{4} T_{ij} \quad 0 \le HDI_i \le 1 \tag{2}$$

where

$FMI_i$ = *Form Mingling Index*,

$HDI_i$ = *Tree HDI*,

$V$ = neighbour $j$ belongs to the same crown form as reference tree $i$; 0 otherwise,

$T$ = neighbour j belongs to the same tree height as reference tree $i$; 0 otherwise.

### Statistical analysis

For statistical analysis, SPSS 16.0 statistic software was used. During perceptual testing, the scores assigned by the participants for each landscape were assessed and supplementary statistics regarding the silhouette effect of the landscapes (minimum, maximum, mean and std. deviation) were calculated. Correlation analysis was performed in order to test whether there was a significant relationship between the mean silhouette values and index parameters of the landscapes. A Pearson correlation coefficient was used to assess these relationships. Pearson's correlation coefficient can be used in cases when the data have a normal or nearly normal distribution. The Shapiro–Wilk method was used to test for normality of distribution for all variables. The relationship between the mean silhouette values of the landscapes and *FMI*, *HDI* and *FMI* + *HDI* was analysed using a Pearson correlation coefficient. Where $P > 0.05$, the relevant variable was considered to have a normal distribution (Kalayci 2006; Kayitakire et al. 2006).

## Results and discussion

### Scores assigned to the silhouette effect of landscapes

The landscape silhouette values identified on the basis of respondents answers to the questionnaires ranged between 3.97 and 7.55 (Table 1). Participants allocated low scores to the landscapes that had a single tree species and thus single crown form, with no observable height differences between individual trees. Landscapes 1, 3 and 5 received

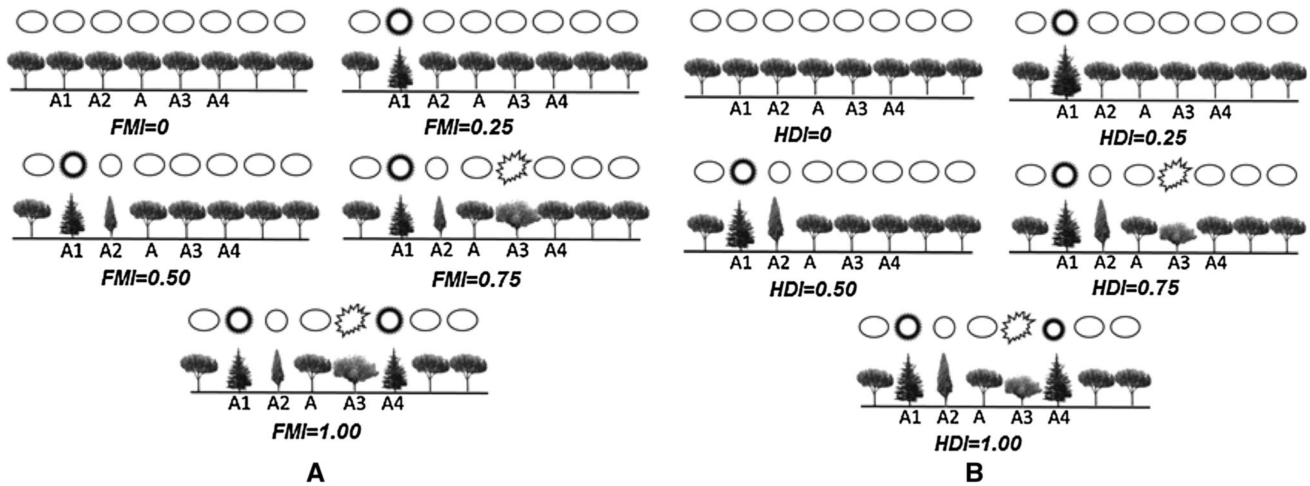


**Fig. 3** Index values of the reference tree in relation to the four neighbour trees (**a**) FMI, (**b**) HDI (A is reference tree; A1, A2, A3 and A4 are neighbour trees)

**Table 1** Descriptive statistics of landscape images

| Descriptive statistics | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. | Min. | Max. | Average score | SD | N | No. | Min. | Max. | Average score | SD |
| 1 | 1 | 6 | 3.97 | 1.33 | 99 | 21 | 3 | 10 | 6.61 | 1.89 |
| 2 | 2 | 7 | 4.12 | 1.34 | 99 | 22 | 4 | 10 | 6.45 | 1.77 |
| 3 | 2 | 7 | 5.27 | 1.55 | 99 | 23 | 2 | 10 | 6.21 | 2.16 |
| 4 | 3 | 7 | 5.36 | 1.22 | 99 | 24 | 5 | 10 | 7.33 | 1.43 |
| 5 | 1 | 7 | 4.15 | 2.09 | 99 | 25 | 4 | 9 | 5.82 | 1.51 |
| 6 | 1 | 8 | 4.64 | 1.76 | 99 | 26 | 3 | 9 | 6.09 | 1.51 |
| 7 | 1 | 9 | 4.91 | 1.67 | 99 | 27 | 2 | 8 | 5.85 | 1.48 |
| 8 | 1 | 8 | 4.79 | 1.73 | 99 | 28 | 3 | 9 | 6.39 | 1.91 |
| 9 | 2 | 9 | 6.12 | 1.89 | 99 | 29 | 2 | 10 | 6.88 | 2.10 |
| 10 | 3 | 8 | 5.91 | 1.68 | 99 | 30 | 3 | 10 | 6.52 | 1.80 |
| 11 | 2 | 7 | 4.58 | 1.54 | 99 | 31 | 3 | 9 | 6.21 | 2.10 |
| 12 | 1 | 7 | 4.82 | 1.19 | 99 | 32 | 4 | 10 | 7.39 | 2.09 |
| 13 | 1 | 8 | 5.09 | 1.97 | 99 | 33 | 3 | 9 | 5.97 | 1.69 |
| 14 | 2 | 9 | 6.06 | 2.04 | 99 | 34 | 4 | 9 | 6.15 | 1.46 |
| 15 | 2 | 9 | 5.42 | 1.82 | 99 | 35 | 2 | 10 | 5.64 | 1.87 |
| 16 | 4 | 10 | 6.91 | 1.44 | 99 | 36 | 5 | 10 | 7.03 | 1.65 |
| 17 | 3 | 10 | 6.52 | 1.77 | 99 | 37 | 3 | 9 | 6.42 | 1.75 |
| 18 | 1 | 7 | 4.91 | 1.63 | 99 | 38 | 4 | 10 | 7.55 | 1.73 |
| 19 | 1 | 8 | 5.15 | 1.86 | 99 | 39 | 2 | 8 | 5.91 | 1.70 |
| 20 | 1 | 10 | 6.27 | 2.05 | 99 | 40 | 3 | 9 | 6.21 | 1.59 |

low scores with mean silhouette values of 3.96, 5.27 and 4.15, respectively (Table 1). The landscapes that had increased crown form diversity scored higher (Table 1). For example, the silhouette values of landscapes 8 and 15 that were originally derived from landscape 1 (by increasing form diversity) were 4.79 and 5.42, respectively (Table 1). The silhouette value of landscape 10 was 5.91, while landscapes 17 and 24 rose to 6.52 and 7.33 due to increased form diversity (Table 1).

The height differences between the individual trees in landscapes 1 and 3, which had the same crown form, increased as did landscapes 2 and 4 had a mean silhouette value of 4.12 and 5.36, respectively (Table 1). The height differences between the individual trees in landscapes 8 and 15 that had different crown forms increased as did landscapes 9 and 16 which had silhouette values of 6.12 and 6.91, respectively (Table 1). Those landscapes that had a homogenous mingling composition in groups (crown

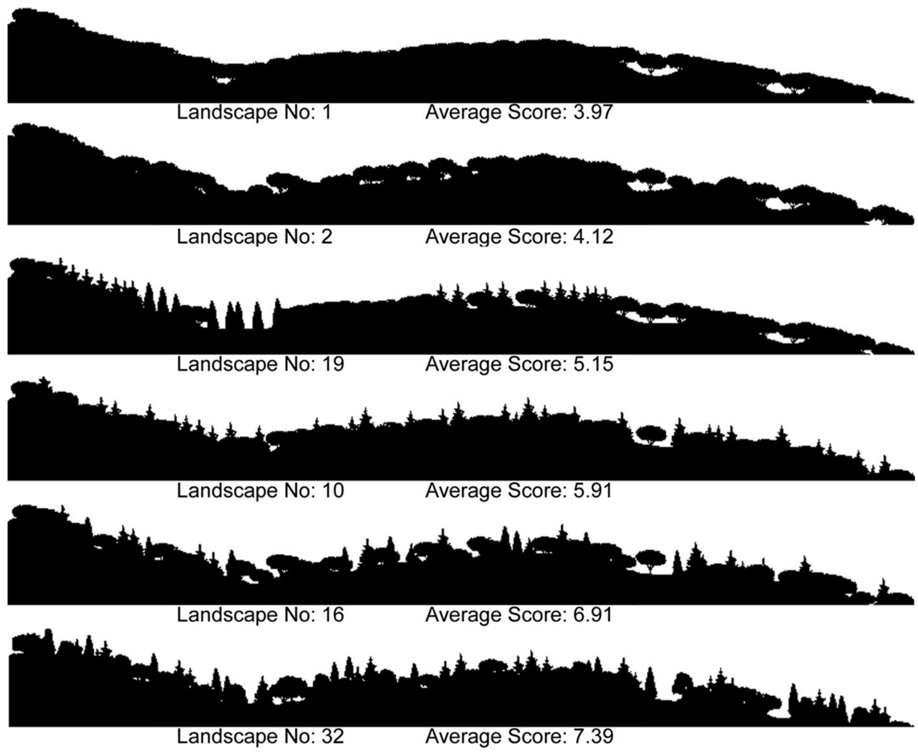


**Fig. 4** Examples of landscapes with high and low silhouette scores

form and height differences) usually had lower silhouette values compared to those landscapes that had a scattered heterogeneous mingling composition. For example, the silhouette values of the landscapes 17 and 24 that had a scattered heterogonous composition with respect to form diversity were found to be 6.52 and 7.33 (Table 1). For landscapes 19 and 27 where the individual trees had more homogenous composition in groups, the silhouette values fell to 5.15 and 5.85, respectively (Table 1). However, when the height difference was added to those landscapes with homogenous composition in landscapes 20 and 28, the silhouette value rose again to 6.27 and 6.39 (Table 1). Landscapes 24, 32 and 38 were scored higher by the participants with silhouette values of 7.33, 7.39 and 7.55 and had type 4, 5 and 6 crown forms, as well as a differentiation in height. In conclusion, as the compositional diversity of the landscapes increases, their visual preference values and thus silhouette values also increased. Low and high silhouette effect scores were observed across the different landscapes (Fig. 4).

The findings from this study have shown that scores assigned by the participants and the structural diversity indices had statistically significant associations. The results of the visual analysis indicated that there was a difference between the silhouette values of landscapes and it was possible to make a choice based on the silhouette value. The silhouette value of landscapes ranged from 3.97 to 7.55. Therein, tree crown diversity was observed to have a positive impact on the silhouette value of landscapes. Landscapes with a single crown form were preferred less, while those landscapes with increased form diversity were more attractive. Although the silhouette value of a landscape also increased with the increased form diversity, it was understood that form diversity had a limited positive impact on silhouette value. There was a significant difference between the silhouette that contains trees with a single crown form and silhouettes containing four different forms, whereas silhouette values were very close once there was greater than four forms. This indicates that the participants found the landscapes similar in aesthetic terms after a certain number of form diversity had been reached. It was also observed the vertical layers had a positive impact on silhouette effect. This effect comes from the differences in heights found in forests that contained a greater number of tree species. This effect was also enhanced from trees within a range of age classes across the landscape. Participants also perceived that landscapes containing trees with different growth forms were more attractive than landscapes with trees having the same growth patterns.

## Relations between structural diversity indices and preference scores

*FMI and HDI* values were calculated in order to determine structural diversity and assess its relationship with the silhouette value of each landscape (Fig. 5). Landscape 2

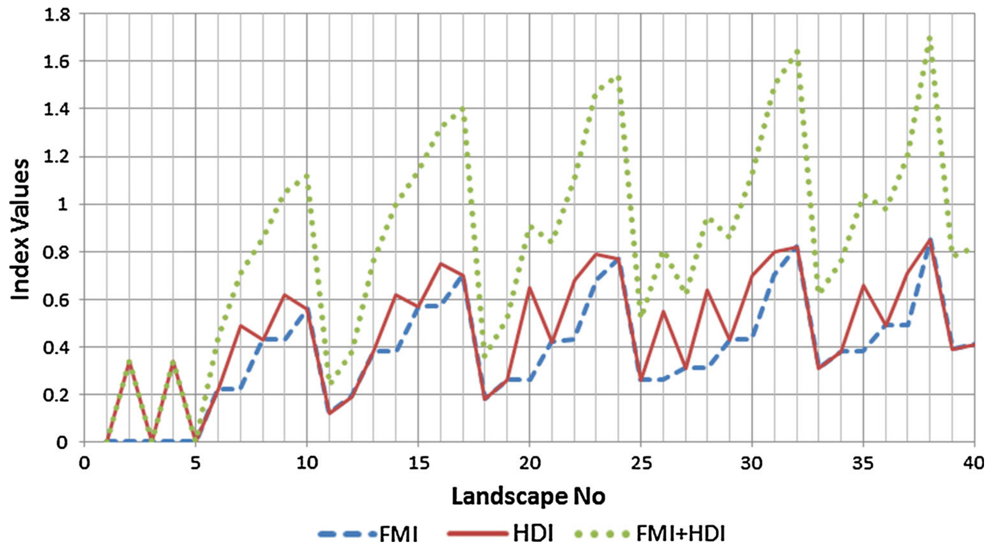


**Fig. 5** Landscape structural diversity indices

**Table 2** Pearson's correlation coefficient between average silhouette score and indices

| | Average silhouette score |
|---|---|
| *FMI* | 0.78 |
| *HDI* | 0.75 |
| *FMI* + *HDI* | 0.80 |

Correlation is significant at the 0.01 level (two-tailed)

scored low in *FMI*, *HDI* and *FMI* + *HDI* values (0, 0.34 and 0.34), while landscape 38 had the highest score with corresponding values of 0.85, 0.85 and 1.70, respectively (Fig. 5). As was expected, the landscapes with low structural diversity were usually considered to be areas with low silhouette values, whereas the landscapes with higher structural diversity had higher silhouette values.

The relationship between structural diversity indices and mean silhouette values of landscapes was found to be similar (Table 2). Strong relationships were found between the silhouette values of the landscapes and the indices calculated for their structural diversity indicators (Fig. 6). A strong and positive relationship was observed between *FMI/HDI* and the silhouette values ($r = 0.78$ and $r = 0.75$, $P < 0.01$). The highest relation with the visual quality of the landscapes was found when the *FMI and HDI* were assessed jointly ($r = 0.80$, $P < 0.01$).

Therefore, it can be suggested that *FMI* and *HDI* can be reliably applied as a method to estimate the silhouette value of a forest landscape. However, the combined effect of *FMI* + *HDI* had the highest association with the landscape silhouette value (Fig. 6). Landscapes with increased crown form diversity and thus high *FMI* value were more often preferred by the participants. Landscapes that had lower *FMI* value (decreased heterogeneity) had lower silhouette values (Fig. 6). Nevertheless, landscapes that had higher *FMI* value (increased heterogeneity) and scattered composition had correspondingly higher silhouette values (Fig. 6). Like *FMI,* landscapes with higher *HDI* values (landscapes consisting of trees at different heights) were found to be more attractive to participants and thus had higher silhouette values (Fig. 6). It was also observed that the silhouette value of a landscape increases if the height difference is improved in landscapes with lower *FMI* and silhouette values. Again this is due to the composition of individual trees and variation in tree form. Therefore, it is anticipated that the silhouette effect of a landscape can be estimated more accurately if *FMI* and *HDI* are used jointly rather than separately (Fig. 6).

As the *FMI* and *HDI* methodology has not previously been applied to studies when assessing landscape silhouette values, we were unable to directly compare these results with any relevant published literature. Nevertheless, it can be said that our findings are consistent with similar studies on visual quality assessment. For example, Ode (2003) argued that stands containing a mix of tree species with a corresponding variety of leaf type and form were preferred more than the stands of a single species, in terms of visual landscape quality. In a similar study conducted by Ribe (1989), it was emphasized that the mingling of species also improved the natural beauty of a landscape. Similarly, de Val et al. (2006) stated that a more heterogeneous landscape had a positive impact on visual quality. However, Golivets (2011) findings differed from the above-mentioned studies in that the mingling of tree species was not found to have a significant influence on participants' choices.

Our results also support previous studies that have investigated the effect of tree canopy layering (tree height

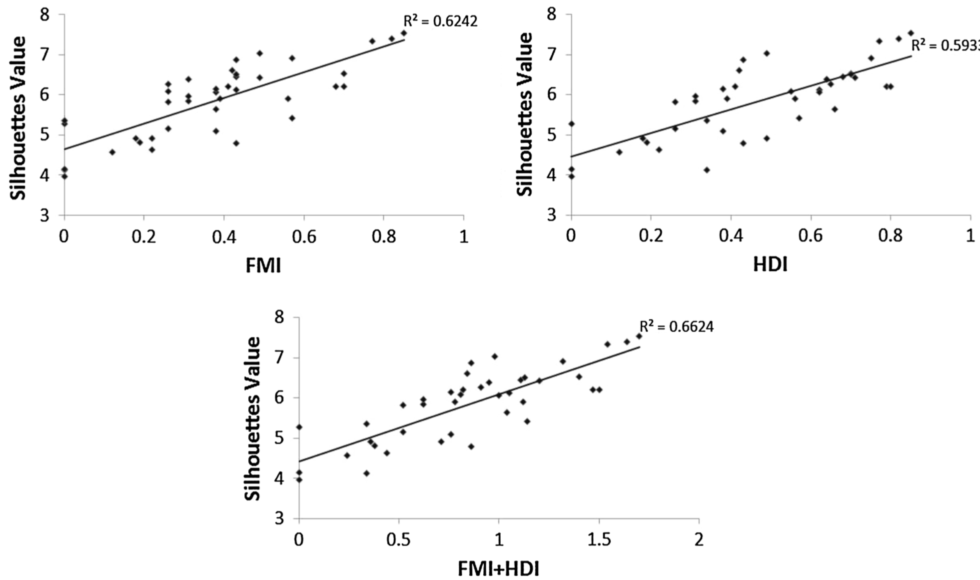


**Fig. 6** Association between the silhouette values of landscapes and structural diversity indexes

diversity) as a means of assessing the aesthetic value of forest landscapes. For example, Silvonnoinen et al. (2001) also found that diversity in tree height had a positive influence on people's choices, while Gundersen and Frivold (2008) argue that people preferred forests that consisted of a mix of both young and old trees. Golivets (2011) concurred, in that mixed stands consisting of trees with different growth rates may be more aesthetically pleasing. Likewise, in a study conducted by Ozkan (2014), it was suggested that in areas with a layered composition, the lower layers consisting of younger or smaller trees had a positive impact on visual quality.

Tree density and its effect on the silhouette value in a landscape are another area of importance when assessing the aesthetic value of urban forests. Gundersen and Frivold (2008) stated that visibility of crowns was an important factor based on participants preferences, with respect to tree species and species mingling. Appropriate vegetation density therefore makes the structural diversity of a landscape visible. Misgav (2000) argued that low vegetation density influenced the visual choices positively, whereas the higher densities had a negative impact. In the same study, it was stated that landscapes with intermediate tree density were the most preferred ones. Secondly, landscapes with low tree density were preferred, while the landscapes with high tree density were preferred the least. Therein, we suggest that further research is required in order to determine the optimum tree density required for improving the silhouette value of urban forest landscapes.

To date, aesthetic value has not been properly incorporated into urban forest management planning. It is our understanding that managers have been seeking effective indices to objectively characterize the aesthetic value of urban forests. The results presented here are a first attempt to use structural diversity indices to assess silhouette value as an important component of aesthetic quality within urban forests. This study found that the *FMI* and *HDI* can be used as an objective measure to estimate silhouette value of an urban forest landscape, as well as being able to monitor for changes in silhouette value over time. Best practice management guidelines utilizing specific silviculture treatments can then be applied in order to improve the silhouette value of urban forest stands located along a skyline. Therefore, the indices developed in this study will have global applications for managers when assessing the aesthetic value of urban forests.

## Conclusion

Determining the silhouette value as a component of aesthetic function based on questionnaires for determining human preferences is time-consuming. We hypothesize that our structural diversity indices may be used for this purpose instead. This study revealed that landscape silhouette value had a positive and strong association with the *FMI* and *HDI*. Therefore, these indices can be used at the planning stage, in order to decide on the best forest structure that will optimize aesthetic value in areas that possess a silhouette effect. Although *FMI* and *HDI* values each had strong association with landscape silhouette values individually, the combined effect of *FMI* and *HDI* values resulted in a much stronger association. Thus, it can be concluded that the silhouette value of a landscape increases as the compositional diversity of a landscape (crown form and height difference) also increases. The findings of this pioneering study are promising for future studies on the silhouette value of urban forests. We suggest that further research be undertaken at different locations across the landscape, while at the same time highlighting the need for community involvement from within a broad demographic range of society. This is necessary in order to further strengthen the *FMI* and *HDI* developed in this study to ensure that a robust method of assessment is incorporated into management plans. Therein, future models that can be developed on the basis of *FMI* and *HDI* will be an important tool for managers and planners and assist them to make rapid, cost-effective assessments of the silhouette effect of urban forest landscapes.

**Acknowledgments** We wish to thank the İstanbul University, Faculty of Forestry, for facilitating our study, and the students from the Forest Engineering Department for volunteering to undertake perceptual testing. Without the support of the İstanbul Metropolitan Municipality for allowing us to undertake the necessary fieldwork required, this research would not have been possible. Lastly, we thank Dr. Donna Treby for English editing of our paper.

## References

Aguirre O, Hui G, Gadow KV, Jiménez J (2003) An analysis of spatial forest structure using neighbourhood-based variables. For Ecol Manag 183(1):137–145

Akbar KF, Hale WHG, Headley AD (2003) Assessment of scenic beauty of roadside vegetation in northern England. Landsc Urban Plan 63(3):139–144

Anyanwu EC, Kanu I (2006) The role of urban forest in the protection of human environmental health in geographically-prone unpredictable hostile weather conditions. Int J Environ Sci Technol 3(2):197–201

Arriaza M, Canas-Ortega JF, Canas-Madueno JA, Ruiz-Aviles P (2004) Assessing the visual quality of rural landscapes. Landsc Urban Plan 69(1):115–125

Asan U (2013) Orman Amenajmanı Esasları (Temel Kavramlar, Amaçlar ve İlkeler). İ.Ü. Yayınları, İstanbul

Asan U, Yeşil A, Çalışkan A, Özkan UY, Destan S, Sağlam S, Karlıoğlu N, Yaylacı İ (2013) Emirgan Korusu Amenajman-Silvikültür Planı. 2013–2022, İstanbul

Bell S, Blom D, Rautamäki M, Castel-Branco C, Simson A, Olsen I (2005) Design of urban forest. Urban forests and trees. Springer, Berlin, pp 149–186

Bishop ID, Rohrmann B (2003) Subjective responses to simulated and real environments: a comparison. Landsc Urban Plan 65(4):261–277

Bulut Z, Yilmaz H (2008) Determination of landscape beauties through visual quality assessment method: a case study for Kemaliye. Environ Monit Assess 141(1–3):121–129

Clark PJ, Evans FC (1954) Distance to nearest neighbour as a measure of spatial relationships in populations. Ecology 35:445–453

Clay GR, Daniel TC (2000) Scenic landscape assessment: the effects of land management jurisdiction on public perception of scenic beauty. Landsc Urban Plan 49(1):1–13

Daniel TC (2001) Whether scenic beauty? Visual landscape quality assessment in the 21st century. Landsc Urban Plan 54(2001):267–287

Daniel TC, Meitner MJ (2001) Representational validity of landscape visualizations: the effects of graphical realism on perceived scenic beauty of forest vistas. J Environ Psychol 21(1):61–72

de Val GDLF, Atauri JA, de Lucio JV (2006) Relationship between landscape visual attributes and spatial pattern indices: a test study in mediterranean-climate landscapes. Landsc Urban Plan 77(4):393–407

Dramstad WE, Tveit MS, Fhellstad WJ, Fry GLA (2006) Relationships between visual landscape preferences and map-based indicators of landscape structure. Landsc Urban Plan 78(4):465–474

Dwyer F, McPherson EG, Scroeder HW, Rowntree RA (1992) Assessing the benefits and costs of the urban forest. J Arboric 18(5):227–234

Gadow KV, Hui GY, Albert M (1998) The neighbourhood pattern: a new parameter for describing forest structures. Centralblatt Gesamtes Forstwesen 115:1–10

Golivets M (2011) Aesthetic values of forest landscapes. Dissertation, Swedish University of Agricultural Sciences

Gundersen VS, Frivold LH (2008) Public preferences for forest structures: a review of quantitative surveys from Finland, Norway, Sweden. Urban For Urban Green 7(4):241–258

Hartig T (1993) Nature experience in transactional perspective. Landsc Urban Plan 25(1):17–36

Herzog TR (1984) A cognitive analysis of preference for field and forest environments. Landsc Res 9(1):10–16

Holdridge LR (1967) Life zone ecology. Tropical Science Center, San JoseÂ

Hui GY, Albert M, Gadow KV (1998) Das Umgebungsmaß als Parameter zur Nachbildung von Bestandesstrukturen. Forstwissenschaftliches Centralblatt 117(1):258–266

Hulliv R, Revell GRB (1989) Issues in sampling landscapes for visual quality assessments. Landsc Urban Plan 17(4):323–330

Kalayci S (2006) SPSS applied multivariate statistical techniques. Asil Publishing, Ankara

Kayitakire F, Hamel C, Defourny P (2006) Retrieving forest structure variables based on image texture analysis and IKONOS-2 imagery. Remote Sens Environ 102(3):390–401

Konijnendijk CC, Ricard RM, Kenney A, Randrup TB (2006) Defining urban forestry- a comparative perspective of North America and Europe. Urban For Urban Green 4(3):93–103

Liao CH, Chang CY, Chiueh PT (2013) Correlation between land-use change and greenhouse gas emissions in urban areas. Int J Environ Sci Technol 10(6):1275–1286

Lohr VI, Pearson-Mims CH (2006) Responses to scenes with spreading, rounded and conical tree forms. Environ Behav 38(5):667–688

Mansfield C, Pattanayak SK, McDow W, McDonald R, Halpin P (2005) Shades of Green: measuring the value of urban forests in the housing market. J For Econ 11(3):177–199

Meitner MJ (2004) Scenic beauty of river views in the Grand Canyon: relating perceptual judgments to locations. Landsc Urban Plan 68(1):3–13

Misgav A (2000) Visual preference of the public for vegetation groups in Israel. Landsc Urban Plan 48(3):143–159

Müderrisoğlu H, Eroğlu E, Özkan Ş, Ak K (2006) Visual perception of tree forms. Build Environ 41(6):796–806

Ode A (2003) Visual aspects in urban woodland management and planning. Dissertation, Swedish University of Agricultural Sciences

Ode AK, Fry GLA (2002) Visual aspect in urban woodland management. Urban For Urban Green 1(1):15–24

Ode A, Fry G, Tveit MS, Messager P, Miller D (2009) Indicators of perceived naturalness as driver of landscape preference. J Environ Manag 90(1):375–383

Ozdemir I, Karnieli A (2011) Predicting forest structural parameters using the image texture derived from WorldView-2 multispectral imagery in a dryland forest, Israel". Int J Appl Earth Obs Geoinf 13(5):701–710
Ozkan UY (2014) Assessment of visual landscape quality using IKONOS imagery. Environ Monit Assess 186(7):4067–4080
Palmer JF, Hoffman RE (2001) Rating reliability and representation validity in scenic landscape assessments. Landsc Urban Plan 54(1):149–161
Panagopoulos T (2009) Linking forestry, sustainability and aesthetics. Ecol Econ 68(10):2485–2489
Qin X, Meitner MJ, Chamberlain BC, Zhang X (2011) Estimating visual quality of scenic highway using GIS and landscape visualizations. http://proceedings.esri.com/library/userconf/proc08/papers/papers/pap_1540.pdf. Accessed 14 Oct 2014
Ribe RG (1989) The aesthetics of forestry: what has empirical preference research taught us? Environ Manag 13(1):55–74
Sander H, Polasky S, Haight RG (2010) The value of urban tree cover: a hedonic property price model in Ramsey and Dakota Counties, Minnesota, USA. Ecolog Econ 69(8):1646–1656
Shannon CE, Weaver W (1949) The mathematical theory of communication. University of Illinois Press, Urbana
Silvonnoinen H, Alho J, Kolehmainen O, Pukkala T (2001) Prediction models of landscape preferences at the forest stand level. Landsc Urban Plan 56(1):11–20
Simpson EH (1949) Measurement of diversity. Nature 163:688
Summit J, Sommer R (1999) Further studies of preferred tree shapes. Environ Behav 31(4):550–576
Tveit MS (2009) Indicators of visual scale as predictors of landscape preference; a comparison between groups. J Environ Manage 90(9):2882–2888
Tveit M, Ode A, Fry G (2006) Key concepts in a framework for analyzing visual landscape character. Landsc Res 31:229–255
Tyrväinen L, Pauleit S, Seeland K, Vries D (2005a) Benefits and uses of urban forests and trees. Urban forests and trees. Springer, Berlin Heidelberg, pp 81–114
Tyrväinen L, Silvennoinen H, Kolehmainen O (2005b) Ecological and aesthetic values in urban forest management. Urban For Urban Green 1(3):135–149
Tyrväinen L, Gustavsson R, Konijnendijk C, Ode A (2006) Visualization and landscape laboratories in planning, design and management of urban woodlands. For Policy Econ 8(8):811–823
Voeks RA, Rahmatin M (2004) The providence of nature: valuing ecosystem services. Int J Environ Sci Technol 1(2):151–163
Zhang M, Wang D, Wang Z, Zhang X, Zhang G, Xu Y (2014) Individual aesthetic differences evaluation of Yan'an Urban forests in the loess plateau China. Int J Multimed Ubiquitous Eng 9(10):329–340