Study on evaluation of lightscape under forests in urban parks

Xinchen Hong¹,², *, Xiaojia Nie¹, Zhongwei Dai¹, Siren Lan¹

¹College of Arts & Landscape Architecture, Fujian Agriculture and Forestry University, Fuzhou, China.
²Faculty of Forestry, University of British Columbia, Vancouver, Canada.

*Corresponding author e-mail: xch.hung@outlook.com

Abstract. In order to explore the evaluation system of lightscape under forest in the urban park, an evaluation system of lightscape under forest in the urban park was constructed, which was composed of physical factors, psychological factors and spatial factors and the corresponding 12 indexes affecting the lightscape based on Grey Statistical Theory and Analytic Hierarchy Process. The results show that: 1) Psychological and physical factors are the dominant influencing indexes in the evaluation system, and the weight accounting of these factors is more than 70%. 2) The total weight of illumination uniformity is higher than other evaluation indexes. 3) The important indicators and sub-important indicators that affect the evaluation of lightscape under forest in the urban park are as follows: illumination Uniformity, satisfaction of lightscape, audio-visual coordination, sky View Factor, daylight factor under forests, perception of privacy, perception of security and clear bole height, etc. The evaluation system is expected to provide theoretical basis and effective methods for the future study in urban light environment.

1. Introduction

Lightscape is a recently proposed concept in visual landscape, which has gradually become a research hotspot in recent years. The lightscape is mainly composed of light source, light shadow and its changes, and the lightscape can be divided into two categories, natural lightscape and artificial lightscape. Dobler et al. [1] find that the lightscape of residential area and commercial district is relatively concentrated based on the dynamic changes of urban artificial view by aerial photography. Bennie et al. [2] explores the characteristics of biological activity in urban nightscape by simulating the lighting environment at night. Hale et al. [3] explores the change of lighting environment with building density and land use, and find the positive correlation between artificial lighting index and building density. Through previous researches, scholars have enriched some aspects of the study for lightscape, but there are few reports on the lightscape under forest in urban parks.

2. Method

2.1. Screening evaluation index

From the point of view of urban lightscape and forest space [4, 5, 6, 7, 8], the evaluation of lightscape under forest in urban parks is mainly influenced by photophysical indexes, space under forests and human’s perception. Thus, in this study, the factors influencing the lightscape evaluation were divided
into three aspects: physical factors, psychological factors and spatial factors, and 20 indexes were selected from these three aspects.

According to the actual situation of urban parks and natural lightscape, this study adopts Delphi method and Likert's 7 points method (level 1 represents strongly unimportant, level 7 is strongly important, grades 2 to 6 are between the two). And the method determines the importance of each indicator. In addition, a total of 20 experts with background of urban forest and lighting environment were invited to independently judge the degree of important indicators from the perspective of lightscape under forests in urban parks.

2.2. Grey Relational Analysis

The importance of primary evaluation indicators for lightscape was classified by three ash classes: The high degree of importance, the normal degree of importance and the low degree of importance. The equations are as follows:

\[
f_1(m) = \begin{cases} 
  1 & r_m \geq 7 \\
  \frac{r_m - 4}{7 - 4} & 4 < r_m < 7 \\
  0 & r_m \leq 4 
\end{cases},
\]

\[
f_2(m) = \begin{cases} 
  0 & r_m \geq 7 \\
  \frac{7 - r_m}{7 - 4} & 4 < r_m < 7 \\
  1 & r_m = 4 \\
  \frac{r_m - 1}{4 - 1} & 1 < r_m < 4 \\
  0 & r_m \leq 1 
\end{cases},
\]

\[
f_3(m) = \begin{cases} 
  0 & r_{mn} \geq 4 \\
  \frac{4 - r_{mn}}{4 - 1} & 1 < r_{mn} < 4 \\
  1 & r_{mn} \leq 1 
\end{cases},
\]

In the equations, \( f_k(m) \) denotes the whitening function of the degree of importance for the \( m \) evaluation index as \( k \) grade evaluation, and \( r_m \) indicates the importance evaluation value \( i \) for the \( m \) evaluation index.

Then, the grey class decision coefficients and decision vectors were calculated.

\[
\{\eta_1(m), \eta_2(m), \eta_3(m)\} = \{\sum g_1(m) \cdot f_1(m), \sum g_2(m) \cdot f_2(m), \sum g_3(m) \cdot f_3(m)\}.
\]

In the equation: \( \eta_k(m) \), \( k = (1, 2, 3) \) denotes that the decision coefficient of the \( m \) evaluation index belongs to \( k \) grey class, \( g_k(m) \) indicates that the number of experts to evaluate the importance of the \( m \) evaluation index \( k \) grade. \( f_k(m) \) is obtained from the results of equations (1)-(3). The results of the screening indicators are shown in Table.1.
Table 1. The importance degree of the evaluation index of lightscape under forest in urban park based on grey statistical theory

| Lightscape factor | Pre-selected evaluation index | Decision vector | Degree of importance | Selection |
|-------------------|------------------------------|-----------------|---------------------|-----------|
|                   |                              | η1   | η2       | η3       |            |           |
| Physical factors  | Illuminance extremum         | 4.67 | 11.67    | 3.66     | Normal    | ×          |
|                   | Illumination uniformity      | 11.67| 7.67     | 0.67     | High      | √          |
|                   | radiant illumination         | 2.33 | 7.67     | 10.00    | Low       | ×          |
|                   | Daylighting coefficient      | 15.00| 4.00     | 1.00     | High      | √          |
|                   | Excitation purity            | 5.67 | 11.33    | 3.00     | Normal    | ×          |
|                   | Brightness ratio             | 11.33| 7.33     | 1.33     | High      | √          |
|                   | Colour temperature           | 10.33| 9.00     | 0.67     | High      | √          |
|                   | Rendering index              | 4.67 | 11.00    | 4.33     | Normal    | ×          |
| Psychological factors | Lightscape comfort        | 9.33 | 9.67     | 1.00     | Normal    | ×          |
|                   | Lightscape scarification     | 11.67| 4.67     | 3.66     | High      | √          |
|                   | Audio-Visual coordination    | 14.33| 4.67     | 1.00     | High      | √          |
|                   | Light-Shadow suitability     | 5.33 | 13.00    | 1.67     | Normal    | ×          |
|                   | Privacy                      | 11.33| 8.00     | 0.67     | High      | √          |
|                   | Security                     | 10.00| 7.67     | 2.33     | Normal    | ×          |
|                   | Sky view factor              | 11.00| 4.67     | 4.33     | High      | √          |
| Spatial factors   | Vertical structure richness  | 8.67 | 9.33     | 2.00     | Normal    | ×          |
|                   | Clear bole height            | 14.00| 4.67     | 1.33     | High      | √          |
|                   | Stand density                | 12.33| 5.00     | 2.67     | High      | √          |
|                   | Crown density                | 9.33 | 8.33     | 2.33     | High      | √          |
|                   | Leaf area index              | 3.00 | 11.33    | 5.67     | Normal    | ×          |

2.3. Analytic Hierarchy Process

After the Grey Relational Analysis, the indexes of high importance degree were screened out. The evaluation system of lightscape under forests in urban parks was constructed based on physical factors, psychological factors and spatial factors, including 12 Index layers.

In order to determine the relative importance of the indexes in each layer and within the layers, the judgement matrix \( A \) was established by Analytic Hierarchy Process. The judgment matrix \( A \) represents the scale of the relative importance of the factors \( A_i \) and \( A_{ij} \) relative to the upper layer of elements, and the value of the judgment matrix reflected the relative importance of each factor. For the importance of lightscape under forests in urban parks, 20 experts with background of urban forest and lighting environment were invited through expert investigation. In addition, they should use the 9-quartile scale to assign the importance of the indicators according to the actual situation in urban forests. Then the judgment matrix was normalized and the weight coefficient of the evaluation index was obtained. Finally, the consistency test was carried out.

3. Results

3.1. Ranking of weights of evaluation indexes

Through the previous section, the weight and the total ranking of each evaluation index in the evaluation system of lightscape under forests in urban parks were obtained (see Table 2).
### Table 2. Evaluation index weight distribution table

| The first layer | The second layer          | Weight | The third layer | Weight   | Total weight | Sort |
|-----------------|---------------------------|--------|----------------|----------|--------------|------|
| Physical factors| Illumination uniformity   | 0.4525 |                | 0.1446   | 1            |      |
|                 | Daylighting coefficient   | 0.2489 |                | 0.0795   | 7            |      |
|                 | Brightness ratio          | 0.1520 |                | 0.0486   | 9            |      |
|                 | Colour temperature        | 0.1466 |                | 0.0468   | 11           |      |
| Psychological factors | Lightscape scarification | 0.3147 |                | 0.1294   | 2            |      |
|                  | Privacy                   | 0.2224 |                | 0.0914   | 5            |      |
|                  | Security                  | 0.1914 |                | 0.0787   | 8            |      |
|                  | Audio-visual coordination | 0.2715 |                | 0.1116   | 3            |      |
| Spatial factors | Sky view factor           | 0.3731 |                | 0.1005   | 4            |      |
|                 | Clear bole height         | 0.3271 |                | 0.0881   | 6            |      |
|                 | Stand density             | 0.1221 |                | 0.0329   | 12           |      |
|                 | Crown density             | 0.1777 |                | 0.0479   | 10           |      |

As is shown in Table 2, it can be seen that psychological factors account for the largest weight, followed by physical factors and spatial factors in the second layer of spatial landscape evaluation under urban parks. The weights of the three factors are 0.3195 and 0.4111 and 0.2694, respectively, which indicates that psychological and physical factors play a key role in the study of landscape factors that influence the lightscape of urban parks, accounting for more than 70% of the factors in the evaluation system.

In the third layer, illumination uniformity $>$ lightscape satisfaction A21 $>$ Audio-visual coordination $>$ Sky view factor $>$ privacy $>$ clear bole height $>$ daylighting coefficient under forests $>$ security $>$ brightness ratio $>$ crown density $>$ color temperature $>$ stand density. The illumination uniformity in physical factors is 0.1446, which is much higher than other evaluation indexes. The weight of degree of lightscape satisfaction and audio-visual coordination in psychological factors and sky view factor in spatial factors were higher, which were 0.1294 and 0.1116 and 0.1005, respectively. And the brightness ratio and colour temperature in physical factors, stand density and crown density in spatial factors are less important to other indexes, leading to the total weight of 0.0486, 0.0468, 0.0329 and 0.0479, respectively.

#### 3.2. Classification of evaluation indexes

According to the total weight value, 12 evaluation indexes in the third layer were divided into three categories: important indexes (more than 0.1000), secondary important indexes (0.0500 to 0.1000) and general indexes (less than 0.0500).

The results showed that the important indexes include illumination uniformity, lightscape satisfaction, audio-visual coordination and sky view factor, and total weight sum is 48.61%. Secondary important indexes include the daylighting coefficient under forests, privacy, security and clear bole height, and the total weight sum is 33.78%. The general indexes include brightness ratio, color temperature, stand density and crown density, and the sum of total weight is 17.62%. In the future research on the evaluation of lightscape in urban parks, we can pay attention to the influence of the important indexes and the secondary important indexes on the lightscape evaluation.

#### 4. Conclusion

Grey statistical theory and analytic hierarchy process have been widely used in the evaluation of urban park landscape in recent years. In this study, the grey statistical theory was used to screen the evaluation
indexes, and then the analytic hierarchy process was used to construct the evaluation system of lightscape under forests in urban parks.

The quantitative evaluation of lightscape in urban parks is the application trend of urban light planning, protection, utilization and development. The grey statistical theory and the analytic hierarchy process can analyze the factors that affect the urban parks based on different levels and qualitatively and quantitatively. In addition, this study tend to provide a reference for the scientific and systematic study about the theory and method of light environment in the future.

Acknowledgments
This work was financially supported by the Funding of Engineering Research Center for Forest Park of National Forestry and Grassland Administration, China (grant number PTJH1500217), and the Social Science Foundation of Fujian, China (grant number FJ2018B087 and FJ2016C043).

References
[1] Dobler G., Ghandehari M., Koonin S. E., et al., Dynamics of the urban lightscape. Information Systems, 2015, 54 (C) 115-126.
[2] Bennie J., Davies T. W., Inger R., et al., Mapping artificial lightscape for ecological studies. Methods in Ecology & Evolution, 2014, 5 (6):534-540.
[3] Hale J. D., Gemma D., Fairbrass A. J., et al., Mapping Lightscape: Spatial Patterning of Artificial Lighting in an Urban Landscape. Plos One, 2013, 8 (5) e61460.
[4] Parkins K. L., Elbin S. B., Barnes E., Light, Glass, and Bird—Building Collisions in an Urban Park. Northeastern Naturalist, 2001, 22 (1) 84-94.
[5] Yan H., Wu F., Dong L., Influence of a large urban park on the local urban thermal environment. Science of the Total Environment, 2018, s 622–623:882-891.
[6] Fauset S., Gloor M. U., Aidar M. P., et al., Tropical forest light regimes in a human-modified landscape. Ecosphere, 2017, 8 (11) e02002.
[7] Dongmei Y. E., Mingfeng X. U., Jiang Q., et al., Effects of different forest types on understory light and radiation reduction. Hunan Forestry Science & Technology, 2016.
[8] Rowe G., Wright G., The Delphi technique as a forecasting tool: issues and analysis. International Journal of Forecasting, 2013, 15 (4) 380-381.