Evaluation of urban light-emitting diodes lighting facilities’ impact on landscape shrub

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Abstract. In the field of urban lighting and landscape planning, most researchers focus on how to make lighting meet people's demand, while few researchers consider the impact of lighting systems on landscape plants. Based on statistical methods and field measurements, the brightness data of street lamps in a street of Shanghai were collected, and these data were compared to the shrub growth data of the street green belt. The results show that LED street lighting facilities have a promotion effect on the growth rates of shrub's new shoots, while it also have effect on shrub leaves’ greenness. This study discussed a statistically method to evaluate the impact of urban lighting system on landscape plants, providing theoretical and methodological support for urban lighting and ecological landscape design. Besides, this study could also help further study about the impact of urban lighting on Urban ecosystem.

1. Introduction
With urbanization process, many big city’s development mode were gradually transitioning from incremental development to inventory optimization, this makes scholars pay more attention to the optimization of urban infrastructure [1]. However, most researchers focus on reviving the economic vitality of old urban areas or designing spectacular lighting systems to enrich city's nighttime landscape, few pay attention to urban lighting infrastructure’s impact on plant. There are many potential problems in the existing urban lighting facilities, one of which is artificial light’s impact on urban ecosystem. Light-emitting diodes (LED), which are widely used in urban lighting systems, have been shown to affect plant growth. Avercheva et al [2] studied the effects of high pressure sodium lamp on the growth of several crops and found LED light can affect plant growth. Nhu et al [3] found Light-emitting diodes were better at promoting Phalaenopsis and Cymbidium plantlet’s growth than fluorescent bulbs. Since light-emitting diodes have an impact on the growth of crops and some flower plants, it would be meaningful to study the effects of urban lighting on landscape greenery. Studying on landscape plant’s health first appeared in the 1960s, Cumming et al [4], Boone R and Westwood R [5] discussed the evaluation system of tree health and made a systematic evaluation of tree health. However, few of these evaluation indicators involve the impact of artificial lighting on the health of shrubs in cities, and there is still a gap in indicators applicable to the evaluation of urban lighting facilities’ effect on shrub. In order to fill this gap, this study developed a set of evaluation tables reflecting shrub growth status of street greenbelt, based on this evaluation table, the influence of LED street lamps on shrub growth was evaluated.
2. Materials and Methods

2.1. Overview of the research subjects
The study was conducted in Shanghai (120°52’ E–122°12’ E, 30°40’ N–31°53’ N), a coastal city in east China. In Shanghai, LED energy-saving lamps were widely used in street lighting. On branch roads, street lamps are often set in green belts full of shrubs. A typical road in Fengxian district with eleven street lamps and two green belts were chosen for our measurements, all street lamps were LED energy saving lamps with rated power of 30W. Lamp’s designed lighting radius was 2.5 meters, and the lamp is generally in an equidistant distribution relationship with trees in the green belt. The distance is 4 meters and the radius of tree canopy is 2-2.3 meters. Our experiment was started in 15th June, summer. Which is the most vigorous period of time for shrub plant’s growth.

2.2. Establishment of shrub growth status index
Based on Avercheva et al[2] and Nhut et al[3]'s research, the growth rate of new shoots and greenness of plant leaves were selected as shrub growth indexes for they reflect the influence of light on plants best. Field measurement was carried out on the basis of quadrat, with each street lamp as the origin, dividing a quadrat in the green belt every 50 cm in lamp’s northward until the designed lighting radius was reached and so did in the southward. The lamps were numbered as L1 to L11.

The growth rate of new buds was shown by the average height of new shoots in a quadrat one month after all the green belts had been pruned to the same height. after the pruned, the height of each quadrat would be measured immediately, and they would be measured again a month after.in the second measurement, the length of the new shoots of each quadrat would be measured and the average length value would be regard as the data of the quadrat. The greenness of plant leaves would be evaluated based on Royal Horticultural Society (RHS) Large Colour Chart (table 1), each plant in each quadrat would be scored, the average score would be regard as the data of the quadrat.

2.3. Illumination measurement
The GM1020 digital illuminometer was selected as the light intensity measuring instrument, the measurement accuracy is 0.1lx. To reflect the degree to which each quadrat is affected by LED lighting, we starting from a street lamp, measure the intensity of light every 50 cm in a straight line until reach lamp’s designed lighting radius.

3. Results and Discussion

3.1. LED lighting facilities’ impact on Photinia new shoots’ growth rate
The measurement and statistical results confirm that LED street lamps have a significant impact on the growth rate of Photinia new shoots (table2, 3 and 4, figure 1). In most quadrats, the overall trend is that the further away from street lamps, the lower the average length of new shoots. Quads from the street lamp of 2 to 2.5 m were shaded by trees during the day and exposure to light from 0 to 5.3 lx at night. Those quadrats have the lowest average new shoots length. On the contrast, quadrats from the street lamp samples of 1.5 to 2 m get plenty of sunshine during the day and exposure to light from 5.3 to 8.7 lx at night. These quadrats have the longest average new shoots length. For quadrats within 1.5 m of the street lamp, the closer the quadrats to the lamp, the longer their new shoots are. Li[6] and Kepenek[7]'s research shown that LED lights promote the growth of plant shoots and roots, generally consistent with the observation results of this study. The result that quadrats 1.5 to 2 m away from lamp have the longest average new shoots length was most likely due to contingency factor and larger sample size could reduce the occurrence of similar errors in future’s measurement.

3.2. LED lighting facilities’ impact on Photinia leaves’ growth rate
According to the measurement and statistical results, the greenness of Photinia leaves is negatively correlated to the intensity of LED light. (Table2, 5 and 6, figure 2). For quadrats within 1.5m of lamp,
the farther the distance from the lamp, the greener their leaves were. Quadrats of 1 to 1.5 m away from lamp have the highest greenness score and quadrats of 1.5 to 2.5 m away from lamp have lower scores than them, while quadrats of 0 to 0.5 m away from lamp have the lowest scores. Considering previous studies have shown that LED light can promote the synthesis of chlorophyll in leaves [8], the most reasonable explanation for the observed results is that the growth rate of new shoots is higher than the rate of chlorophyll synthesis, which leads to the decrease of leaf greenness. Besides, the shading effect of trees and the contingency caused by small sample size could also affect the measurement results.

4. Conclusions
This study explored a method to evaluate the impact of LED street lamps on landscape shrubs based on measurement and statistics, so as to provide new methods and ideas for urban ecological landscape design. Based on previous researches, a table include plant growth rate and plant leaf greenness index was created to assess the impact of LED street lighting on shrub growth. Through the field measurement, tables and figures could reflect lamp’s impact on shrub were made. According to the measurement and statistical results, the LED lamps widely used in Shanghai urban area have a great impact on the growth rate of new shoots and leaf greenness of shrubs, the degree of influence is closely related to the intensity of light. Unreasonable LED street lamp planning is likely to cause problems such as irregular shrub growth and inconsistent leaf greenness, thus creating a negative impact on urban plant landscape planning and increasing the maintenance cost of urban plant landscape. Besides, there are still some defects in this experiment. In order to reach a more accurate and reliable conclusion, this experiment should measure more samples and consider more factors.

Table 1. greenness of plant leaves evaluation based on RHS Large Colour Chart

| Grading | Evaluation standard                  |
|---------|-------------------------------------|
| 1       | Yellowish green E                   |
| 2       | Light Yellowish green D             |
| 3       | Brilliant Yellowish green C         |
| 4       | Brilliant Yellowish green B         |
| 5       | Vivid Yellowish green A             |

Table 2. Relationship between light intensity and linear distance from street lamps

| Distance | light intensity(lx) |
|----------|---------------------|
| 0cm      | 28                  |
| 50cm     | 23.3                |
| 100cm    | 17.4                |
| 150cm    | 8.7                 |
| 200cm    | 5.3                 |
| 250cm    | ≤1                  |

Table 3. average height of new shoots on the north side of each street lamp (Unit: cm)

| Quadrat 1 (di=50) | Quadrat 2 (di=100) | Quadrat 3 (di=150) | Quadrat 4 (di=200) | Quadrat 5 (di=250) |
|-------------------|--------------------|--------------------|--------------------|--------------------|
| L1                | 8.32               | 0                  | 0                  | 0                  |
| L2                | 4.55               | 2.23               | 2.68               | 2.77               | 2.31               |
| L3                | 7.58               | 4.01               | 4.31               | 2.25               | 6.74               |
| L4                | 2.63               | 4.63               | 4.56               | 5.85               | 7.63               |
| L5                | 8.35               | 7.11               | 3.62               | 2.85               | 3.14               |
| L6                | 3.27               | 7.15               | 6.53               | 7.26               | 2.15               |
| L7   | 4.21 | 1.98 | 0   | 0   | 2.94 |
| L8   | 9.31 | 7.19 | 3.68 | 2.01 | 4.81 |
| L9   | 0    | 0    | 0   | 0   | 3.68 |
| L10  | 4.32 | 4.12 | 3.85 | 2.16 | 1.57 |
| L11  | 0    | 0    | 0   | 0   | 0   |

Table 4. average height of new shoots on the south side of each street lamp (Unit: cm)

| Quadrat 1 (di=50) | Quadrat 2 (di=100) | Quadrat 3 (di=150) | Quadrat 4 (di=200) | Quadrat 5 (di=250) |
|-------------------|-------------------|-------------------|-------------------|-------------------|
| L1                | 7.83              | 5.61              | 5.32              | 0                 | 3.40              |
| L2                | 1.89              | 1.64              | 0.87              | 1.40              | 0.88              |
| L3                | 3.32              | 4.16              | 1.61              | 0                 | 7.15              |
| L4                | 2.34              | 4.82              | 6.33              | 2.88              | 8.29              |
| L5                | 7.18              | 6.86              | 7.15              | 5.42              | 6.43              |
| L6                | 7.88              | 8.32              | 7.69              | 9.63              | 2.98              |
| L7                | 8.64              | 5.11              | 5.13              | 6.35              | 3.87              |
| L8                | 1.55              | 3.21              | 2.23              | 0                 | 0                 |
| L9                | 5.32              | 4.87              | 5.56              | 8.23              | 2.98              |
| L10               | 3.21              | 3.56              | 3.45              | 2.69              | 1.23              |
| L11               | 2.23              | 2.35              | 4.21              | 4.11              | 3.65              |

Table 5. Plant leaf greenness rating on the north side of each street lamp

| Quadrat 1 (di=50) | Quadrat 2 (di=100) | Quadrat 3 (di=150) | Quadrat 4 (di=200) | Quadrat 5 (di=250) |
|-------------------|-------------------|-------------------|-------------------|-------------------|
| L1                | 4                 | 0                 | 0                 | 0                 | 0                 |
| L2                | 2                 | 2                 | 3                 | 3                 | 1                 |
| L3                | 2                 | 2                 | 3                 | 3                 | 3                 |
| L4                | 3                 | 3                 | 2                 | 1                 | 3                 |
| L5                | 3                 | 4                 | 2                 | 2                 | 3                 |
| L6                | 3                 | 3                 | 3                 | 3                 | 3                 |
| L7                | 1                 | 3                 | 3                 | 0                 | 5                 |
| L8                | 3                 | 4                 | 5                 | 4                 | 4                 |
| L9                | 0                 | 0                 | 0                 | 0                 | 5                 |
| L10               | 4                 | 4                 | 5                 | 4                 | 4                 |
| L11               | 0                 | 0                 | 0                 | 0                 | 0                 |

Table 6. Plant leaf greenness rating on the south side of each street lamp

| Quadrat 1 (di=50) | Quadrat 2 (di=100) | Quadrat 3 (di=150) | Quadrat 4 (di=200) | Quadrat 5 (di=250) |
|-------------------|-------------------|-------------------|-------------------|-------------------|
| L1                | 4                 | 4                 | 2                 | 0                 | 3                 |
| L2                | 2                 | 2                 | 3                 | 2                 | 2                 |
| L3                | 3                 | 3                 | 4                 | 0                 | 3                 |
| L4                | 2                 | 2                 | 2                 | 3                 | 2                 |
| L5                | 3                 | 3                 | 4                 | 4                 | 4                 |
| L6                | 2                 | 2                 | 5                 | 4                 | 4                 |
| L7                | 1                 | 3                 | 3                 | 5                 | 4                 |
| L8                | 4                 | 5                 | 5                 | 0                 | 0                 |
| L9                | 4                 | 5                 | 5                 | 3                 | 2                 |
| L10               | 2                 | 3                 | 3                 | 3                 | 4                 |
| L11               | 3                 | 3                 | 5                 | 4                 | 4                 |
5.2 4.68 4.37 6.2 2.99

Figure 1 Relationship between the length of the new shoots and the distance from the street lamp

4 3.16 3.53 3.2 3.32

Figure 2 how the leaves’ greenness level changed with its distance between the lamps

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