THE EFFECT OF ARTIFICIAL ILLUMINATION ON POSTPONING PLANT PHENOLOGY

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Abstract. The phenology of landscape plural can predict the urban environment and guide the development of the city. The aim of the study is to get the relationship between urban environment and plant phenology. The methods monitored the phenology of the environment and garden plants in the main urban area of Chongqing from 2016 to 2019. And it is concluded that artificial light of garden lighting is between 1000 to 4000 Lx in Chongqing, and the application of LED (Light Emitting Diode) is the highest number. At the same time, the flowering period of trees is more susceptible than that of the shrubs; the flowering period of plants is more susceptible than the evergreen plants; and the fruit period of trees is earlier; the flowering period is prolonged. The flowering stage and flowering period of pruning plants are longer than the plants under natural state. This data should prove useful for future research of the subject.

Keywords: *nightscape lighting, plant phenology, garden plants, environment and phenology*

Introduction

The urban environment has a great impact on plant phenology. Since 1950, the flowering period of urban garden plants has moved 1~3 days ahead in Europe (Menzel, 2002), and from 1902 to 2006, the flowing period for the shrub species in nearly 1/4 of North America also came much earlier (Neil, 2010). In China, the spring phenological period of most plants in urban areas has moved to an earlier date, and the autumn phenological period was delayed (Caruso, 2004). In particular, from 1963 to 2007, the early flowering period of 34 woody plants came 9 days ahead of time, and the full-bloom stage 12 days earlier (Bai et al., 2010). In recent years, nightscape lighting have been widely applied in urban areas above the county level in China, and so far spread to scenic tourist areas and some natural mountains. To celebrate Hangzhou G20 Summit, more than one billion RMB was invested in nightscape, which further triggered the construction of nightscapes in various cities. Now landscape plants have been illuminated at night everywhere in China (Yuan, 2014) The light environment is an important factor affecting plant growth. According to the biological rhythm, plants do not perform photosynthesis at night (Zhang et al, 2012). However, with the artificial lighting, the photosynthesis time of plants is prolonged, affecting their phenology. There is a close relationship between light and plant photosynthesis (Kendrick, 1986). Unlike daylight, the light source intensity, spectral energy distribution and illumination time of artificial light all affect plant phenology (Fukuda et al, 2008).

Chongqing is located in Class V light climate zone in China. It is in the southwestern part of China and the upper reaches of the Yangtze River, falling within the subtropical climate zone, with an average annual temperature of 16~18 °C, an annual rainfall of

1017.5 mm and a sunshine duration of 1000~1400 h. This city has abundant garden plants, so a large amount of lighting facilities have been built. This paper attempts to study the phenology of garden plants in Chongqing, with a view to finding out the impacts of artificial lighting on the urban forestry ecosystem.

Materials and methods

Selection of materials

25 observation points with landscape lighting in the main urban area of Chongqing were selected for monitoring of landscape lighting and plant phenology. The research location is in *Figure 1*. The parameters recorded included artificial illumination, temperature, humidity and altitude. In each survey area, 20 sampling sites were randomly selected for measurement and each measurement was repeated 3 times. The criteria for material selection were that it had an ornamental value and that it was widely distributed in Chongqing. There were 36 species of woody garden plants, including 16 species of shrubs (8 evergreen and 8 deciduous shrubs) and 20 species of arbors (5 evergreen and 15 deciduous arbors). The selected plants fell within 14 families and 21 genera (see *Table 1*).

Figure 1. Research location in Chongqing

Research method

From January 2017 to December 2018, a total of 36 species of woody plants were monitored. The phenological observations were carried out on specific plants at fixed points in accordance with the Chinese Phenological Observation Method (Wan, 1979) every 4 to 7 days. Each time, the observation on all plants in a survey area must be completed within 3 days. The tree species selected were middle-age plants that were

robust and had been blossomed and fruited for more than 3 years. In each survey area, 3-5 plants were observed for each species, including at least 15 branches. During the phenological observation, records and pictures were taken. According to the Julian daily conversion method, the length of the corresponding flowering period and the growing season are calculated. In this study, the bud stage, the early flowering stage, the full-bloom stage and the late flowering stage were defined as the flowering phenology; the bud opening stage, the early leaf expansion and the leaf flourishing stage as the leafing phenology; and the bud opening period, the early leaf expansion, the leaf flourishing stage and the leaf fall stage as the leaf phenology. Artificial illumination is measured by professional illuminance meter.

Table 1. Observation sample land environment factor data table (2016~2019)

Site	Illumination (lx)	Temperature (°C)	Humidity	Altitude (m)	Architecture proportion (%)	Hard ratio (%)	Plant coverage (%)
1.Guanyinqiao Street	4860	23.21	50.27	265.70	51.18	48.82	13.25
2.Nanping pedestrian	2890	24.90	53.27	290.70	45.93	54.07	16.00
3.Sanxia pedestrian	4050	22.88	48.76	243.90	33.37	66.63	16.85
4.Chunhui Road	1700	25.20	44.54	283.00	23.23	69.02	37.21
5.Daping Street	3980	24.01	56.01	328.80	9.83	38.53	50.30
6.Geleshan Street	1030	20.49	47.97	507.60	33.33	60.01	29.96
7.Jinxing Avenue	2020	23.03	50.80	325.80	40.66	53.41	17.01
8.Shuangyuan Avenue	2510	23.31	47.83	273.80	22.24	69.99	26.37
9.Xiaolong kan Street	2630	22.53	45.34	252.40	18.76	73.12	23.20
10.Xiaoyuan Road	2560	23.10	47.25	275.50	20.26	71.77	33.37
11.Xinnan Road	3020	23.11	57.19	267.20	1.55	40.95	55.12
12.Zhanxi Road	1020	22.51	45.23	252.80	16.14	75.47	25.72
13.The Yangtze River	2200	22.81	59.92	337.33	15.21	76.31	23.76
14.Xinan University	1310	21.35	47.86	265.90	23.14	19.19	55.13
15.Chongqing University	810	22.68	51.61	237.70	27.26	28.41	41.14
16.Yixueyuan Road	2320	21.26	49.08	327.09	27.01	32.97	40.73
17.Dadukou Park	1010	22.45	56.74	279.10	13.25	12.47	63.37
18.Zoo	2020	22.93	42.07	255.70	7.35	16.81	62.77
19.Eling Park	2910	22.27	59.62	347.67	6.37	12.82	64.19
20.Administrative center	3210	22.01	47.88	276.78	2.96	9.68	66.36
21.Huahui Park	2820	21.24	54.01	283.80	4.02	18.43	47.13
22.Shapingba Park	1810	21.80	46.79	250.80	2.38	8.26	82.43
23.Geleshan Park	510	19.38	54.00	573.80	0.82	5.18	59.78
24.Nanshan plant Park	1100	21.05	49.60	525.50	6.80	15.14	74.36
25.Zhaomushan Park	5530	20.95	52.22	460.80	0.83	2.59	94.10

Results

Artificial light source types in garden lighting

The types of artificial light sources in garden nightscape were analyzed with the survey data, through which, the utilization of these light sources were obtained, as shown in *Figure 1*. According to statistics, the garden nightscape sources mainly include metal halide lamps, high pressure sodium lamps and LEDs. Traditional light sources accounted for 20% of the total surveyed ones, followed by white LEDs (39%),

yellow LEDs (6.8%), red LEDs (5.4%), violet LED (2.7%) and green LED (2.5%). Due to the transient nature, long service life and high luminous efficiency, LED light is gradually replacing the traditional light source as the dominant light source in landscape lighting (Pousset et al, 2010).

Illumination of artificial light sources in garden lighting

At present, the illumination intensity of garden nightscape lighting is generally high, resulting in extremely serious light pollution. Statistics of the illumination intensity applied in garden lighting are shown in *Figure 2*. As can be seen, the illumination intensity of garden nightscape lighting ranges mainly between 1000~4000 lx, accounting for 74% of the quantity surveyed; the illumination intensity for key plants ranges between 5000~6000 lx, accounting for 14% of the total surveyed quantity; most fluorescent lighting has an intensity of 1000 lx or below, accounting for 12% of the total quantity. In the garden lighting practice, an illumination intensity of 1000~4000 lx can meet people's usage and aesthetic needs, and such intensity is also the most widely applied (Duan, 2015).

Phenological characteristics of plants in the urban environment

36 plants radiated by artificial light sources were observed, and the averages of the flowering period (early flowering, full blossom and late flowering) and the mature fruiting period were compared with those recorded in Flora of China, Flora of Chongqing Jinyun Mountain and Flora of Sichuan. According to *Table 2*, among the 36 observed plants, 18 showed obviously earlier flowering periods, and 5 experienced earlier fruiting periods. All other plants showed consistent phenological periods with those recorded (see *Table 2*).

Phenological sensitivity of plants in the urban environment

The plants experiencing earlier flowering periods included 2 species of evergreen shrubs, accounting for 25% of all evergreen shrubs; 5 species of deciduous shrubs, accounting for 63% of all deciduous shrubs; 3 species of evergreen arbors, accounting for 60% of all evergreen arbors; and 8 species of deciduous arbors, accounting for 53% of all deciduous arbors. In terms of the fruiting period, the evergreen shrubs, deciduous shrubs and evergreen arbors had consistent phenological periods with the historical records, and only 5 of the deciduous arbors experienced earlier fruiting, which accounted for 45% of all deciduous arbors (see *Fig. 2*).

Figure 2. Life type and advance proportion

Table 2. Historical comparison of plant phenology

Plant name	Florescence			Fruit period		
	Observation (month)	Record	Change	Observation	Record	Change
Pittosporum tobira (Thunb.) Ait.	Late April	Mar to May	-	Mid-Sep	Sep to Oct	-
Loropetalum chinense Oliv. Var. Rubrum Yieh	Late Feb to Mid-April	Apr to May	Advanced	*	*	*
Michelia figo (Lour.) Spreng.	Late March to early May	Mar to May	-	*	Jul to Aug	-
Jasminum mesnyi Hance	Late March to Early April	Dec to Aug	Advanced	*	Mar to May	-
Gardenia jasminoides Ellis var. grandiflora Nakai.	Late May	Mar to July	-	*	May to Dec	-
Gardenia jasminoides Ellis	Mid-May to Early Jun	Mar to July	-	*	May to Dec	-
Camellia japonica L.	Late Jan to Late Mar	Jan to Apr	-	*	*	*
Nandina domestica	Mid-May to Early Jun	Mar to Jun	-	Early Sep	May to Nov	-
Cercis chinensis	Early Mar to Early Apr	Mar to Apr	-	Mid-Aug	Aug to Nov	-
Rhododendronsimsii&R. spp.	Early Mar to Late Apr	Apr to May	Advanced	Mid-Aug	Aug to Nov	-
Rhododendron simsii Planch.	Late Apr to Late May	Jun to Aug	Advanced	Early Nov	Nov to Dec	-
Chimonanthus praecox (Linn.) Link	Early Jun to Mid-Mar	Mar to Apr	Advanced	Early Jun	Apr to Dec	-
Magnolia liliiflora Desr.	March	to Mar	-	Early Sep	Aug to Sep	-
Ligustrum × vicaryi Hort	Late Apr to Late Apr	May to Jun	Advanced	Mid-Jul	Jul to Aug	-
Ligustrum sinense Lour.	Late Mar to Late Apr	Mar to Jun	Advanced	Mid-Oct	Sep to Dec	-
Chaenomeles speciosa (Sweet) Nakai	Mid-Feb to Mid-Mar	Feb to Apr	-	Early Sep	Sep to Oct	-
Michelia alba DC.	March	Apr to Sep	Advanced	*	*	*
Michelia chapensis Dandy	Early Mar to Late Apr	Mar to Apr	-	*	Aug to Sep	-
Michelia maudiae Dunn	Early Feb to Early Mar	Feb to Mar	-	*	Sep to Oct	-
Cinnamomum japonicum Sieb.	Late Mar to Late Apr	Apr to May	Advanced	Late Aug	Jul to Sep	-
Cinnamomum porrectum	April	May to Jun	Advanced	Late Aug	Jul to Sep	-
Michelia alba DC.	Early Feb to Early Mar	Feb to Mar		Late Aug	Aug to Sep	-
Magnolia soulangeana Soul.-Bod.	Late Feb to Late Mar	Feb to Mar		Late Aug	Aug to Sep	-
Acer palmatum 'Atropurpureum'	Apr	May	Advanced	Late Jun	Sep	Advanced
Lagerstroemia indica L.	Mid-Jun to Mid-Sep	Apr to Sep	-	Late Oct	Sep to Dec	-
Prunus Cerasifera Ehrhar f. atropurpurea (Jacq.) Rehd.	Late Feb to Late Mar	Mar to Apr	Advanced	Late May	Aug to Sep	Advanced
Prunus × blireana cv. Meiren	Early Feb to Early Mar	Mar to Apr	Advanced	*	*	-
Malus halliana Koehne	Late Feb to Late Apr	Mar to Apr	Advanced	Mid-Aug	Sep to Oct	Advanced
Malus halliana Koehne	Mid-Mar to Early Apr	Mar to Apr	-	Early Aug	Aug to Sep	-
Amygdalus persica L.	Late Feb to Late Mar	Mar to Apr	Advanced	Early Aug	Aug to Sep	-
Prunus persica 'Atropurpurea'	Late Mar to Mid-Apr	Mar to Apr	-	Late Aug	Aug to Sep	-
Prunus mume	Feb	Dec to Mar	-	Mid-Jun	-	*
Prunus x yedoensis	Mar	Apr	Advanced	Mid-Apr	May	Advanced
Cerasus serrulata	Late Mar to Mid-Apr	Mar to Apr	-	*	*	*
Cerasus subhirtella (Miq.) Sok.	Mid-Feb to Early Mar	Apr	Advanced	Early Apr	May	Advanced
Cerasus serrulata (Lindl.) G. Don ex London	Early Mar to Early Apr	Apr to May	Advanced	Late Apr	*	*

Through comparative analysis, as shown in *Figure 2*, the flowering period of the arbors under artificial lighting changed more obviously than that of the shrubs, and that of the deciduous plants experienced more obvious changes than the evergreen ones. Of the species in life forms experiencing earlier flowing periods, most are deciduous shrubs and deciduous arbors, and their proportions were also high in terms of quantity. However, in terms of the fruiting period, only deciduous arbors experienced earlier fruiting, which was consistent with the results regarding the flowering period.

Plant phenology under the urban management mode

An independent sample T test was performed on the selected woody plants to analyze the phenological differences between different landscape management modes. The survey areas of Chinese Loropetalum herb included the Three Gorges Square, Xinnan Road, Southwest University, Chongqing University, Zoo, Eling Park, Shaping Park, Flower Garden, and Nanshan Botanical Garden; those of *Michelia figo* included Eling Park and Nanshan Botanical Garden; and those of the sample plots of *Ligustrum sinense* included Daping, Star Avenue and Flower Garden. The analysis results are shown in Figure 3.

Under landscape lighting, after being pruned, the bud stage, the early flowering stage and the full blossom stage of woody plants came significantly later than those in the natural state, but the difference between the two states was not significant in the late flowering stage, nor are those in the bud opening stage, the early leafing stage and the leaf flourishing stage. Data show that, under the natural state, woody plants would blossom earlier and longer, but that there is no difference in leafing, probably because woody plants in the natural state are older and have larger ground diameters, making the flowering period earlier; and also because pruned woody plants will preferentially undergo vegetative growth, which is a response to the environmental change.

Figure 3. Difference phenological period under different garden management modes

Discussion

Artificial illumination has significant impacts on the phenology of woody landscape plants (Wang et al., 2012; Kulchin et al., 2018). The high-pressure sodium lamp has a discontinuous spectrum, with a peak value ranging between 570 and 600 nm; the metal halide lamp has a spectral peak ranging between 500 and 600 nm; the white and yellow LEDs contain much blue and red light; and the chromatic spectrum of LEDs has a narrow range. According to the absorption behaviour of the plant with respect to the light source spectrum, the spectra of low-light-intensity high-pressure sodium lamps and LED colour light sources have little effect on plant growth, while those of white and yellow LEDs and metal halide lamp have obvious impacts thereon. The results of the research verified this conclusion.

Artificial illumination is a direct factor affecting plant phenology and the paper-making plants. The flowering period is more sensitive to artificial light than the fruiting period, so it is more suitable as an indicator of the impact of artificial light on plant

phenology. Through analysis of the differences between the phenological periods of 5 arbors in urban and rural areas, it is found that the phenological period in urban areas is 4 days ahead of that in the rural one (Hu, 2013). This study also finds that artificial light, temperature, floor area ratio and proportion of rigid pavement can promote and extend the flowering and leafing of the plants and delay their defoliation; and that the increase of altitude and vegetation coverage has the opposite effect. For pruned woody plants, the bud, early flowering and full-blossom stages are all significantly later than those for plants in the natural state, but the difference between the two states is not so significant in the bud opening, early leafing and leaf flourishing stages (Jia et al., 2019). There is a certain relationship between the stem diameter of the plant and the flowering period, and after being pruned, woody plants would preferentially undergo vegetative growth under the artificial light (Chen, 2007), resulting in much earlier and longer flowering period of woody plants in the natural state.

Conclusion

The wide application of artificial nightscape lighting in the urban areas affects the phenology of garden plants and does harm to the forest growth, which is not conducive to the urban ecological environment. Through the monitoring on the phenology of garden plants in the artificial light environment in Chongqing, this study preliminarily obtains the current range of landscape illumination, applications of spectra and the phenological changes of garden plants, such as the flowering period and fruiting period, which provide information and data for the research on the phenology of landscape plants in Chongqing and also allow people to see the harm of artificial light environment to the landscape plants and the paper-making plants. Future research will focus on the effects of the illumination intensity, spectral energy distribution and illumination time of artificial light sources on plant phenology so as to provide basis for rational use of artificial lighting.

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