Impact of artificial light on night-time singing behaviour of the swifts

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Abstract. In this study, we explored the effect of artificial light on night-time singing behaviour of the swifts in Summer Palace, Beijing, China. In the summer of 2015, we tested the night-time singing frequencies of the swifts under full-spectrum white, 437.5 nm violet, and 622.5 nm orange light at 5 mW/m², 20 mW/m², and 50 mW/m². It revealed that white and orange light significantly increased the average singing frequency, while violet light pronouncedly raised the singing frequency only at 50 mW/m². The variations in impacting rhythms of the tested light sources leave references for bird-friendly exterior lighting schemes.

1. Introduction

Artificial light at night has raised social concerns for its interference with the behaviours and physiological processes of wildlife. Bird is one of the species being affected by the changing light environment since it relies on the natural photoperiod to entrain important biological rhythms [1, 2]. Studies show that artificial light will affect the birds’ foraging [3], reproduction [4], and orientation [5]. As for the bird’s circadian rhythms, the frequently reported effect of artificial light is the shift in timing of life cycles including earlier dawn singing [4] or later dusk singing [6]. Besides, the extent of shift of the circadian rhythm varied between different species [4]. Based in Tianjin – a city next to the capital Beijing City, we have witnessed how promptly lighting has been expanded in the two cities along with the economic growth. The region of Beijing and Tianjin also possesses abundant wetland resources and is an important stopover of the international bird migratory routes. The rapid growth of artificial light may have changed the night-time environment of numerous bird’s habitats and may have led threats to the bird’s circadian behaviours. The research is necessary to inform the local government about the potential risks of artificial light on disruption of ecological environment.

Therefore, in this study we chose Summer Palace in Beijing as our site and the swifts as our study species. Summer Palace is located in the west suburb of Beijing with superior ecological environment. We did the experiment in Kuoru Pavilion where the swifts were observed inhabiting on the girders after dark and singing till going into sleep. Then we set a full-spectrum white light and two types of monochromatic light at three intensities as the test treatments and studied the characters of the swift’s singings under each light condition. The study aims to obtain the influence pattern of light with specific spectrum and intensity on the swift’s singings, discuss the biological mechanisms underlying the results, and accordingly provide suggestions to the upcoming lighting installations in Summer Palace in order to minimize the disturbing effect of light on the night-time activities of the swifts and some related species.
2. Methods

2.1. Test subject

We decided to study the swifts that migrate to Beijing in the early spring and are found in Summer Palace (Haidian District, Beijing, China, 39°59’N, 116°16’E) each summer. Summer Palace is the Chinese royal garden from Qing Dynasty. It is far from Beijing downtown area and is unaffected by urban artificial light (Fig. 1). A preliminary investigation showed that about 27 swifts were nesting on the girders of Kuoru pavilion in Summer Palace. The swifts were observed to leave the nest at dawn, fly back at dusk (Fig. 2) and roosted at the pavilion ceiling overnight. Singing is an essential way of communication for birds. Referring to the published researches focusing on the impact of artificial light on avian circadian rhythms by analysing the singing behaviours [4, 6], we chose the singing of the swifts as the measure of impact of artificial light on the swift’s night-time behaviours.

![Figure 1. Location of Summer Palace and Kuoru Pavilion.](image1)

![Figure 2. Homing swifts near Kuoru Pavilion at dusk.](image2)
2.2. Experimental procedure
At Kuoru Pavilion in Summer Palace, we studied the night-time singing of the swifts under artificial light in summer 2015. On May 24th we did the control experiment, in which we recorded the singings of the swifts at night with no artificial light treatments. Later from May to June we chose the nights with similar weather conditions to conduct the experiments with light treatments (Fig. 3). Each night with the experiment, we introduced one light treatment for a fifteen-minute experiment after it got completely dark, approximately between 8 to 9 pm. Each light treatment was given a specific spectrum and intensity and was performed once through the experimental period. We employed three types of spectrums, including full-spectrum white, 437.5 nm violet, and 622.5 nm orange at the irradiance of 5, 20, and 50 mW/m², respectively (Table 1). We used a Xenon lamp and specific filters to realize the spectrums.

![Schematic experimental settings onsite.](image)

**Table 1.** Spectra and irradiances of light treatments.

| Experiment No.* | Peak (nm) | Half bandwidth (nm) | Spectrum (nm) | Average irradiance (mW·m⁻²) |
|-----------------|-----------|---------------------|---------------|-----------------------------|
| Control         |           |                     |               | 0.02                        |
| W5              |           |                     |               | 5.16                        |
| W20             |           |                     |               | 19.87                       |
| W50             |           |                     |               | 49.76                       |
| V5              | 437.5     | 13                  | 431.0-444.0   | 4.94                        |
| V20             | 437.5     | 13                  | 431.0-444.0   | 20.19                       |
| V50             | 437.5     | 13                  | 431.0-444.0   | 50.50                       |
| O5              | 622.5     | 26                  | 609.5-635.5   | 4.97                        |
| O20             | 622.5     | 26                  | 609.5-635.5   | 19.84                       |
| O50             | 622.5     | 26                  | 609.5-635.5   | 49.85                       |

*W: White; V: Violet; O: Orange; 5, 20, and 50 refers to pre-set irradiances in mW·m².
Prior to the experimental days, we placed the lamp on the ground within the pavilion, positioned it towards the ceiling and adjusted the irradiance of light to the designated level. We tested the irradiance with the aid of the Spectroradiometer (Sama, range: 300-1100 nm). Since the swifts did not roost at one spot, we averaged the irradiances among all the nests and ensured the tested average value to have an error within 2 % (Table 1). Then we documented the gear for adjusting light to the specified level as the pre-setting for the experiments. On the experimental days, before we introduced the light treatment, we switched on the lamp for 10 minutes elsewhere so that light could remain stable. Then we set the lamp to the position for experiment and adjusted light intensity to the pre-set level. In order to exclude the interference of variable weather conditions in natural light, we examined the irradiances reaching the nests and made slight adjustments of the gear accordingly. Meanwhile, we placed a recorder (SONY, ICD-FX88) at the centre point of the pavilion on the ground. When the average irradiance level was finalized, we started a recording of the singing for fifteen minutes.

After the experiments, we processed the recordings with audio spectrum processing software – Adobe Audition CS6. The sound of the singings was purified via standardization, noise elimination, and filtration. From the recordings, we extracted the number of singings by minute and average singing frequency (times/min) through the fifteen-minute experimental period.

2.3. The setting of light environment
We selected a 2000 W power adjustable Xenon lamp to create the full-spectrum white (Fig. 4), one monochromatic light in short wavelength region (peak: 437.5 nm, colour: violet) and another in long wavelength region (peak: 622.5 nm, colour: orange) (Figs. 5 and 6). The bird's wavelength sensitivity ranges from 350 to 720 nm [7]. Xenon light was selected for its wide spectrum spanning from ultraviolet (< 350 nm) to infrared region (> 700 nm) that covers the swift’s spectrum sensitivity. The two narrow-band spectral lights peaking near the two ends of the bird’s sensitivity (437.5 nm and 622.5 nm) were introduced to explore if light with different spectral energy would stimulate the swift’s sensitivity responses to different degrees.

The lamp was placed in a device with internal reflective coating to produce diffused light. For the monochromatic light treatments, a filter was placed on the top of the device to form narrow wavelength energy (Table 1). The lamp was equipped with a modulator so that the light intensity could be adjusted. Since the swifts roosted behind the ceiling structure, direct glare from the light source to the swifts was excluded.

![Figure 4. Spectral power distribution of white light emitted from Xenon lamp.](image-url)
In order to set the intensity of the light treatments with ecological relevance, we investigated the light intensity in Beidagang Wetland that locates in the suburb of Tianjin, China. We set multiple test points along the roads within the habitats of migratory birds and measured the irradiance level (Table 2, Figs. 7 and 8). We adopted irradiance instead of lux as the measure of light intensity in both the field investigation and this study of the swifts, because irradiance objectively describes the radiant energy that reaches the living beings while lux takes into account the human visual sensation [8]. Test point 1 was near a drilling platform emitting significant amount of light (Fig. 9) and gained the maximum irradiance of 61.2 mW/m²; other test points such as 25 to 31 were hardly affected by artificial light and showed lowest irradiances less than 1.0 mW/m² (Table 2). Another study by our team in this field found that the sleep of Black-winged stilt was not disturbed in the habitat with light less than 2.30 mW/m² but was postponed for nearly two hours in a different habitat with light at 8.95 mW/m² [9]. Considering the finding of the study on Black-winged stilt and the measurements obtained from the field, we tentatively set 5, 20, and 50 mW/m² in this study to identify the threshold above which light may significantly impact the singing behaviour of the swifts.
Figure 7. Locations of aquatic bird habitats in Beidagang Wetland.

Figure 8. Test points set around the bird habitats in Beidagang Wetland.

Figure 9. Night-time drilling operation near Test point 1 in Beidagang Wetland.
Table 2. Irradiances of the test points in Beidagang Wetland, Tianjin.

| Test point | Irradiance (mW·m⁻²) | Test point | Irradiance (mW·m⁻²) | Test point | Irradiance (mW·m⁻²) |
|------------|----------------------|------------|----------------------|------------|----------------------|
| 1          | 61.20                | 11         | 0.73                 | 21         | 8.62                 |
| 2          | 11.60                | 12         | 0.65                 | 22         | 8.89                 |
| 3          | 8.14                 | 13         | 0.46                 | 23         | 9.70                 |
| 4          | 6.59                 | 14         | 0.51                 | 24         | 9.68                 |
| 5          | 4.37                 | 15         | 1.44                 | 25         | 0.19                 |
| 6          | 2.56                 | 16         | 2.07                 | 26         | 0.22                 |
| 7          | 1.91                 | 17         | 2.98                 | 37         | 0.22                 |
| 8          | 1.21                 | 18         | 4.45                 | 28         | 0.30                 |
| 9          | 1.06                 | 19         | 7.33                 | 29         | 0.30                 |
| 10         | 0.94                 | 20         | 7.79                 | 30         | 0.25                 |

3. Results
For the control group, the swifts sang intermittently at a low average frequency of 0.3 times/min (Table 3, Fig. 10). 622.5 nm orange light had largely raised the average singing frequencies at all irradiances (Table 3, Fig. 11). The higher the irradiance was, the more significantly the singing frequencies increased. Different from the discontinuous singings of the control, the swifts exhibited successive singings under orange light.

Table 3. Average singing frequencies in the control and light treatments (times/min).

|                | Control | 5 mW·m⁻² | 20 mW·m⁻² | 50 mW·m⁻² |
|----------------|---------|----------|-----------|-----------|
| Control        | 0.3     |          |           |           |
| Orange         | 40.5    | 50.2     | 87.7      |           |
| White          | 18.1    | 40.0     | 72.7      |           |
| Violet         | 1.0     | 0.7      | 28.7      |           |

Figure 10. Number of swift singings in the control group.
The full-spectrum white light also pronouncedly elevated the average singing frequencies but to a slighter degree when comparing to orange light at each irradiance level (Table 3; Fig. 12). Similar with orange light, white light caused the swifts to sing continuously and led the average singing frequency to increase in a dose-dependent manner.

In contrast, 437.5 nm violet light led the swifts to different singing patterns (Fig. 13). Under 5 mW/m² or 20 mW/m² violet light, the swifts subtly increased the average singing frequencies and presented discontinuous singings as they did in the night of control (Table 3, Figs. 10 and 13). Nevertheless, 50 mW/m² violet light led to continuous singings of the swifts and apparently promoted the average singing frequency to 28.7 times/min.

**Figure 11.** Number of swift singings in orange light treatment at: (a) 5 mW/m², (b) 20 mW/m², and (c) 50 mW/m².

**Figure 12.** Number of swift singings in white light treatment at: (a) 5 mW/m², (b) 20 mW/m², and (c) 50 mW/m².

**Figure 13.** Number of swift singings in violet light treatment at (a) 5 mW/m², (b) 20 mW/m², and (c) 50 mW/m².
4. Conclusion
Three conclusions can be drawn from the results. Firstly, the tested artificial light sources in general disrupted the regular night-time singing of the swifts by increasing the average singing frequencies. The degree to which the swift’s singing was affected is ranked as 622.5 nm orange, full-spectrum white and 437.5 nm violet from the most to the least. Besides, while the swifts just sang casually in the natural circumstance, the tested artificial light showed the tendency to keep the swifts singing continuously except 437.5 nm violet light at lower irradiance levels. Thirdly, under the three spectrums, the swift’s singings increased in a dose-dependent manner with more light.

The variations in impacting rhythms of the light treatments leave references for bird-friendly exterior lighting scheme, in which 622.5 nm orange and full-spectrum white light over 5 mW/m² are strongly discouraged, while 437.5 nm violet light less than 20 mW/m² would be more acceptable. The study also arouses further discussion on the sensitivity of birds to light spectrum. The fact that the swifts reacted to 622.5 nm orange with more frequent singings than 437.5 nm violet does not coincide with the finding that avian non-visual photoreceptors regulating circadian behaviours are more sensitive to short-wavelength light [10]. It is possible that the long-wavelength sensitive visual photoreceptors have played a role in timing the circadian behaviours including the night-time singing. Finally, the effect of the full-spectrum white light lay between orange and violet light. There is the possibility that the full-spectrum white demonstrates a combing effect of the narrow-band wavelengths across the bird’s sensitive spectrum. The study calls for further researches to reveal the actual influence mechanisms of artificial light on the swift’s nocturnal behaviours.

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