A study on the impact of artificial lighting on insect diversity in China's urban ecotone: a case study of Tianjin

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Abstract. This paper analyses the experiments conducted in Tianjin, an important ecological interlocking area in North China, and can basically draw the following conclusions. (1) Tianjin's urban ecological interlocking area is rich in insect species, has good stability, and is more affected by artificial lighting. (2) The attraction of artificial lighting lights to insects has a certain relationship with the spectrum and space, which has a lot to do with the wavelength composition of artificial lighting lights. Although the wavelength increases, the attraction decreases. (3) The attractiveness of white light lamps with a colour temperature of 4500k to insects is greater than that of white light lamps with a colour temperature of 3000k.

1. Introduction
According to the conclusions drawn from some studies on the global night sky brightness survey, most of Europe, nearly half of the area of the United States, and many developing countries in Asia are experiencing night light pollution [1]. The night sky brightness is at least 8 % higher than the natural night level. Artificial lighting is gradually eroding the ecosystem. According to related research, the ecological effect of artificial lighting at night depends on its intensity and spectral composition as well as its flicker rate [2].

Recent studies have shown that insect diversity and abundance have been declining year by year in recent years, and there are signs of acceleration [3]. Insects are the basic component of all terrestrial food webs. Through exploration from ancient times to the present, there are approximately 1,346,900 species of animals in the world that have been identified, of which there are more than 1 million species of insects, accounting for approximately 75 % of the known animal species [4]. Any loss of insect biomass may have a wide range of ecological consequences, and artificial lighting at night mainly affects insects from their size and visual system. The main scope of influence can basically be summarized as time disorientation, space disorientation, rhythm disorder, etc., which are mainly reflected in predation, reproduction, mating, and short-distance migration [5]. At present, urban lighting is in the phase of alternating between the old and the new. Many high-pressure sodium lamps and halogen lamps are replaced by light-emitting diodes (LED), and LED can cause uneven spectral distribution through the principle of fluorescent material toning [6].

2. Methods
In order to ensure that the experimental site meets the characteristics of the urban ecological interlocking area, that is, the relevant area with a certain urban landscape but under relatively natural
control and management in the overall environment, we chose the Tianjin University Jinnan Campus, which was closed due to the epidemic, as our experiment location. Its geographical position is superior, with unconstructed woodland on all sides, and after more than eight months of undisturbed restoration environmental conditions have fully met our needs (Fig. 1).

Figure 1. Experimental location map.

After investigation, we selected three locations to ensure the diversity of the space and surrounding environment. The space can basically be summarized as water side, woodland, and grassland. The water body is chosen to be a natural revetment far away from the main road and away from the park lighting (Fig. 2). Because it has not been trimmed and weeded, the grassland level has been excellent during the experiment, the insect density is high, and the experiment results are rich. The low soil slope to the north of the water body is landscaping. The main planting numbers are pewter, green peach and other places with large crowns and dense planting intervals; grassland is chosen to be located between the water body and woodland with street trees and lawns. The space is relatively open, mainly covered by mixed lawn and Sedum Spectabile Boreau.

In terms of the duration of the experiment, in order to ensure the stability of the ecology, we use a staggered method to conduct the experiment, that is, the experiment is carried out at three points in turn for four rounds.

Figure 2. Photos of the experimental site.
In terms of daily experiment time nodes, every day after the sky disappears completely, the arrangement started. After the overall arrangement was completed, the illuminance of the insect trap under the lamps was adjusted to ensure that each lamp was irradiated to catch the insects. After the board illumination was the same, the wax paper of the insect-catchiing board was uncovered at 8 o'clock to start catching. According to the required dimensions, the insect-catchiing board was replaced every 30 minutes, and the completed insect-catchiing board was put into a wooden box with a wooden grill. The storage was classified. According to the statistics of relevant foreign experimental time, the general experimental time tended to be stable at 4.3 hours, so we controlled the experimental time from 20:00 to midnight for a total of four hours (Table 1).

Table 1. Daily experiment time node.

| Time node     | Content                                      |
|---------------|----------------------------------------------|
| 15:00~18:00   | Maintenance of the laboratory equipment      |
| 18:00~19:00   | Determining the location                     |
| 19:00~20:00   | Placing test tools and levelling the irradiance |
| 20:00~00:00   | Experiment and replacing the traps every 30 min. |
| 00:00~        | Recovery of laboratory equipment and preparation of specimens |

According to the related studies, insects may have three types of photoreceptors or opsins: one is sensitive to ultraviolet wavelengths (300-400 nm), the other one – to short wavelengths (400-480 nm), and the third one – to long wavelengths (480-600 nm) [7]. However, some studies have proved that the photoreceptive area of insects is much larger [8]. Light interference experiments on bumblebees have proved that the peak sensitivity of European bumblebees to light can reach 300-700 nm. Therefore, for the experiment, we chose eight fixed-spectrum LED lamps that basically covered all visible light and two mixed white LED lamps to ensure the full spectrum coverage during this experiment. The spectrum and colour are shown in Table 2.

The insect-catchiing board is made of colourless and odourless sticky shellac (Fig. 3), and the experimental platform is made of aluminium assembly frame structure support. The overall height is about 1 m; the lamp is above the ground at about 90 cm. In order to ensure that the illuminance of the insect-trapping plate is constant, the bracket for placing the insect-trapping plate is adjusted, and the irradiance is controlled by the irradiance meter during adjustment (Fig. 4).

Table 2. Experimental luminaire parameters.

| Spectral wavelength, nm | Colour    | Remarks |
|-------------------------|-----------|---------|
| ——                      | white     | 4500 K  |
| ——                      | white     | 3000 K  |
| 720–730                 | far red   |         |
| 665–675                 | deep red  |         |
| 614–624                 | red orange|         |
| 500–505                 | cyan      |         |
| 520–525                 | green     |         |
| 480–485                 | blue      |         |
| 440–445                 | royal blue|         |
| 365                     | ultra-violet|      |
Figure 3. Insect plate (covered with A3 size white hard cardboard, origin: Zibo, Shandong Province).

Figure 4. Experiment table.

Table 3. Weather conditions during the experiment.

| DATE     | Temp, °C | Weather             | Wind | Power | Rise, 05:48 | Set  | Remark     |
|----------|----------|---------------------|------|-------|-------------|------|------------|
| 20200909 | 21~32    | Sunny to cloudy     | WN   | 3-4   | 05:48       | 18:26|            |
| 20200908 | 22~31    | Cloudy              | WN   | 1-2   | 05:47       | 18:28|            |
| 20200907 | 21~31    | Cloudy              | N    | 1-2   | 05:46       | 18:30|            |
| 20200906 | 22~31    | Cloudy to overcast  | ES   | 3-4   | 05:45       | 18:34| Pause      |
| 20200905 | 22~31    | Cloudy to sunny     | EN   | 1-2   | 05:44       | 18:33|            |
| 20200904 | 20~30    | Cloudy to overcast  | WS   | 1-2   | 05:43       | 18:34|            |
| 20200903 | 19~27    | Cloudy              | WN   | 1-2   | 05:43       | 18:36|            |
| 20200902 | 24~29    | Rain turns shade    | WN   | 3-4   | 05:42       | 18:37| Pause      |
| 20200901 | 23~32    | Sunny to cloudy     | WN   | 3-4   | 05:41       | 18:39|            |
| 20200831 | 21~29    | Cloudy to overcast  | WN   | 1-2   | 05:40       | 18:41|            |
| 20200830 | 24~31    | Cloudy to overcast  | ES   | 1-2   | 05:39       | 18:42|            |
| 20200829 | 24~32    | Cloudy              | ES   | 1-2   | 05:38       | 18:44| Pause      |
| 20200828 | 23~32    | Cloudy              | ES   | 1-2   | 05:37       | 18:45| Pause      |
| 20200827 | 22~30    | Cloudy              | E    | 1-2   | 05:36       | 18:47|            |
| 20200826 | 23~28    | Cloudy to overcast  | ES   | 1-2   | 05:35       | 18:48|            |
| 20200825 | 24~32    | Sunny to cloudy     | WS   | 1-2   | 05:34       | 18:50|            |
In the formal experiment process, one experiment at the three locations is one round, and the interval between two rounds of experiments is one to two days. So, the experiment is performed again at an interval of three to four days at each location to ensure that the insects will not be over-captured and it will not cause the steady state to be destroyed. According to the statistics of the later data, our behaviour of suspending the experiment really protected the restoration of insect populations. Excluding the influence of climate, we did not produce a huge deviation in the number of catches, and from a certain level, it was determined that the insect ecosystem was under the appropriate conditions of the experimental site environment. The ability to restore the environment is strong. The overall experiment time and weather conditions at that time are shown in Table 3.

During the experiment, the climate was relatively stable, no extreme weather occurred, and the temperature was relatively suitable, but the temperature difference between morning and evening was large. During part of the experiment, there would be higher wind speeds in the middle and late stages, which may have a certain impact on the experiment.

3. Results

Although related experiments have proved that the species and total amount of Coleoptera in the insect class are the most widespread in nature, in this experiment we have found that Diptera insects are the main catch species. Perhaps this experimental method is related to the height of the experimental platform’s trap. The directivity of the illumination range of the lamp attracts related insects flying and crawling at low altitudes, and this part is dominated by Diptera, which explains this result.

Through the establishment of multiple linear regression equations, we have preliminarily drawn the following conclusions: there is a significant relationship between the number of insects and the space, date, time, and spectral values. From the perspective of the total number of insects, with the passage of airspace, date, and time, the total number of insects shows a downward trend, and the greater the spectral value, the greater the number of insects.

After categorizing insects by insect order, different insects are affected differently. Specifically, it can be attributed to the following laws:

- For Lepidoptera, Trichoptera, and Orthoptera, time has no significant effect on the number of insects, but with the passage of airspace and date, the number of insects shows a downward trend; at the same time, the smaller the spectral wavelength, the greater the number of insects.
- For Hymenoptera and Coleoptera, space has no significant effect on the number, but with the passage of time, the number of insects shows a downward trend; at the same time, the smaller the spectral wavelength, the greater the number of insects.
- For the Hemiptera and Diptera, the number of insects showed a downward trend with the passage of the overall time and the time of each experiment, and the smaller the spectral wavelength, the greater the number of insects.
- For the Neuropteran, with the passage of space and the time of each experiment, the number of insects shows a downward trend, and the spectral wavelength has no significant effect on the number of insects.
- For Collembola, only the spectral wavelength has a significant effect on the number of insects. The smaller the spectral wavelength, the greater the number of insects.

4. Conclusion

Through this experiment, it can be basically judged that setting up lights in the ecological interlaced area needs to avoid short-wavelength light, namely blue and violet light, to prevent damage to the local insect ecosystem. In the lighting time, the lighting setting after midnight should be reduced as much as possible, the illuminance value of the light should be reduced or all unnecessary lights should be directly turned off to ensure that the biological clock of insects is not destroyed and maintain the stability of the ecological environment.
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