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Impacts of Artificial Lighting at Night on Urban Birds in Shanghai With Citizen Science Data

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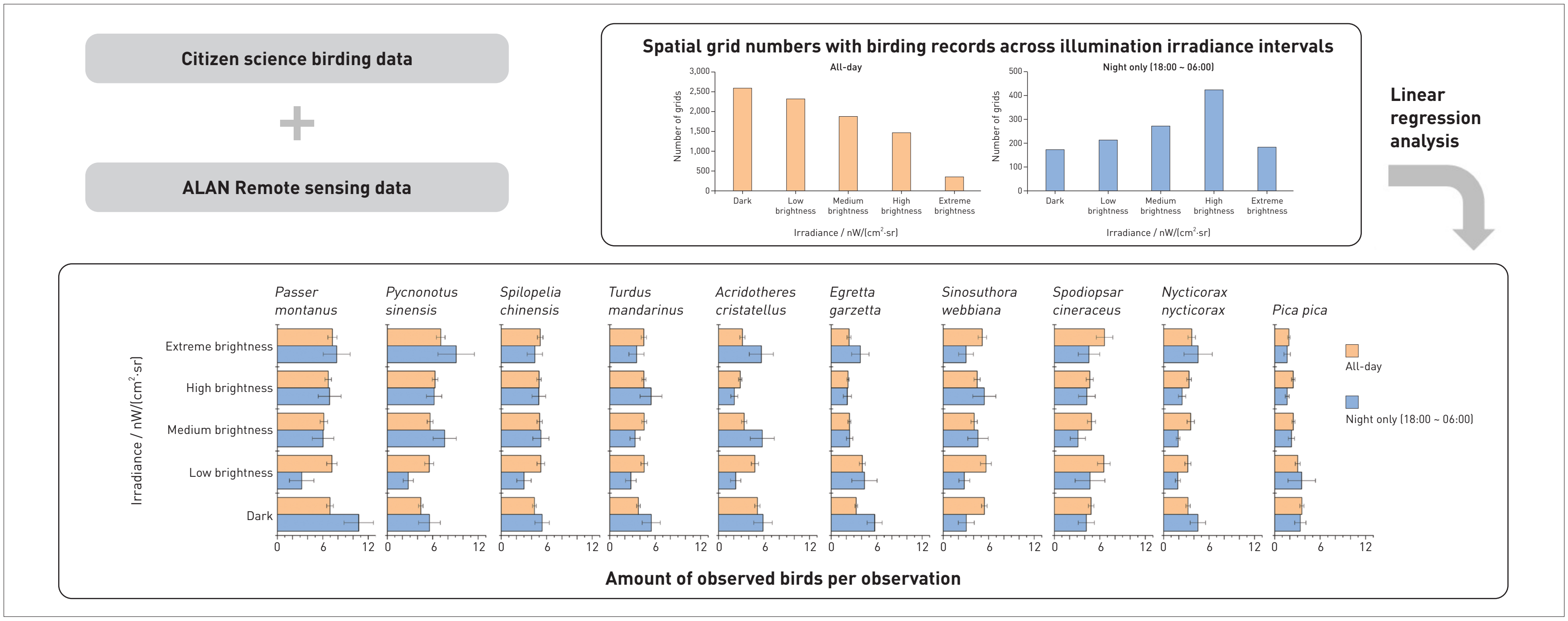
GRAPHICAL ABSTRACT



ABSTRACT

Artificial light at night (ALAN) is an essential infrastructure to support nighttime functions while serving as a significant indicator for urban vitality and economic development. However, the increasing prevalence of artificial lighting in urban areas threatens the health of urban residents of all kinds. Citizen science data are characterized by large sample size and complete spatio-temporal coverage, which have promising application prospects in ecological investigation and related research. In this context, focusing on Shanghai as the study area, this research explores the impact of nighttime light intensity on the distribution of urban birds. Using birding data from China Bird Report, from 2017 to 2023, ten common bird species were selected for the analysis. Based on ALAN remote sensing data, observed bird number varies as illumination radiance increases, revealing three patterns across species: decreasing, multimodal, and balanced. Specifically, most bird species were observed distributed in the lower light irradiance interval, i.e., 0 ~ 0.15 nW/(cm^2·sr), while a few species, such as *Nycticorax nycticorax* and *Passer montanus*, exhibited an aggregation in higher light irradiance intervals at 75 nW/(cm^2·sr) or above. The study revealed a

preliminary correlation of the light irradiance and the distribution of urban bird species with a threshold of light irradiation for bird preference, providing evidences and strategic guidelines to reduce light pollution and improve bird-friendly nighttime environment in cities.

KEYWORDS

Urban Birds; Artificial Light at Night; Bird Distribution; Light Irradiance; Light Pollution; Citizen Science Data

HIGHLIGHTS

- Artificial light at night may affect urban birds in distribution, and observed bird number varies as illumination radiance increases, revealing three patterns across species: decreasing, multimodal, and balanced
- Investigated birds generally preferred lower light irradiance, while a few species can adapt to higher light irradiance
- Citizen science data are characterized by larger sample size and wider spatio-temporal coverage and can complement systematic bird surveys

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1 Background

Landscape lighting has multiple functions such as illumination, environmental beautification, and artistic decoration. However, intensive artificial light at night (ALAN) may have serious impacts on wild lives and organisms[1]~[3]. The “Tribute in Light” landscape lighting installation in New York, an iconic symbol for commemorating the September 11 attacks, causes about 160,000 birds deaths every year[4].

Birds are among the species most affected by light pollution[5]. ALAN affects birds’ photoperiodic perception, disrupting their circadian rhythms, behavioral patterns, and hormone secretion, and altering their seasonal reproduction, immune function, and metabolic rate[6][7], which are detrimental to bird health[8] and can even affect the survival rates of urban-resident birds[9]~[11]. Nocturnal birds, especially migratory birds in flight orientation, have a greater percentage of optic rod cells in the retina for sensing light intensity[12][13] and are therefore more sensitive to increased light levels[14][15]. Existing research has shown that *Parus major* are observed altering their sleeping behavior under 1.6 lux of illumination[16] and their exposure to white light can lead to reduced immune function and an increased risk of malaria infection[17]. Similarly, reduced melatonin release is observed in *Turdus Merula* exposed to 0.3 lux of illumination[18]. *Passer montanus* exposed to simulated urban lighting conditions are observed with lower melatonin levels and reduced species diversity and richness of the gut flora[19].

Biological research on the nighttime artificial lighting environment based on ALAN remote sensing data has focused on the identification of areas impacted by artificial light[20][21], and the relations between ALAN and migratory birds[22][23]. Studies have shown that light pollution has a considerable impact on urban bird diversity, i.e. bird diversity decreases with increasing irradiance[24]. The degree of impact also varies by different bird species: insectivorous and omnivorous birds are more negatively affected, while carnivorous birds are nearly unaffected[25]. Birds that primarily inhabit forests show significant declines in density due to artificial light, whereas birds living in farmland environments are more tolerant of artificial light to some extent[26]. However, the impacts of light pollution on the distribution of different bird species are not fully understood: existing studies rarely address the critical thresholds of radiance affecting bird distributions at the urban scale[27], and visually-sensitive light spectrums of different bird species in the same region is not clear[23]. Most of the data used in such studies have relatively lower spatial accuracy, such as nighttime light remote sensing data (resolution greater than 500 m) from NPP VIIRS, DMSP/OLS, etc.[20][25][26], which limits the guide of these research findings for urban planning.

Currently, many countries and regions have implemented measures to reduce the impact of light pollution on birds. Since 2001, the DarkSky International has certified more than 200 International Dark Sky Places, which are required to “use quality outdoor lighting, effective policies to reduce light pollution, ongoing stewardship practices, and more”[28]. In 2019, New York City required all new buildings to use bird-friendly glass filters to reduce building-related fatalities[29]; three years later, a landmark light-related bill was introduced, requiring most non-essential outdoor lighting to be turned off or covered after 23:00[30]. In China, the official implementation of Shanghai Municipal Environmental Protection Regulations became the nation's first local environmental regulation on light pollution[31].

Unlike traditional bird data collection methods such as field investigations[32] and GPS tracking[33], which are highly time-costly therefore low-scale, "citizen science" data is low-cost and large-scale. Citizen science, generally refers to the invited or voluntary participation of non-experts in the collection, organization, and analysis of data, in order to solve scientific problems[34]. Citizen science data, with an average annual recording number of birds in the millions, can offer new possibilities to characterize the abundance, distribution, and functional composition of bird species at large spatial and temporal scales and to test hypotheses, showing great potential for revealing spatial–temporal dynamics of geographic phenomena[35][36]. Although their data are subject to temporal and spatial distribution bias, studies have proven that citizen science data can be used as a reliable source of data through scientific processing methods. On the one hand, the use of big data modeling to analyze individual differences in the ability of participants to detect and identify birds can exclude high-risk participants[37]; on the other hand, the accumulation of citizen science data up to a certain threshold can reach the level of research validity[38]. Species distribution modeling can also be used to improve the even sampling of citizen science data[37]. Birding enthusiasts can upload their observations of bird species and locations on platforms such like eBird, China Bird Report, and Movebank, and these citizen science databases are now widely adopted in research[38].

This study innovatively combines ALAN remote sensing data and citizen science data, taking the urban area of Shanghai as a case study, to explore the relationship between ALAN intensity levels and bird behavioral patterns, contributing to the development of a bird-friendly nighttime environment in cities. It seeks to answer the following research questions: How might ALAN, as an important support for urban activities and vitality[39][40], affect the behavioral patterns of birds in urban areas? Are there preferred illumination irradiance intervals for birds? And, how should urban management coordinate ALAN and bird conservation?

2 Research Methods

2.1 Definition of Nighttime

Nighttime is generally referred to as the period from dusk to dawn when the sun is below the horizon (below −6° solar azimuth)[41]. The nighttime in this research was defined as the period from 18:00 to 06:00 the next day, covering the crepuscular time spans when most birds are more active and typical urban lighting hours[42].

2.2 Selection of Study Site

In this research, Shanghai's city domain was taken as the study area, with a total area of 6,340.5 $km^2$①. Shanghai is a key stopover on the East Asia–Australasian Flyway for migratory birds[43]. By the end of 2022, a total of 519 species of wild birds, from 22 orders and 79 families, had been recorded within the study area, which accounted for approximately one-third of all bird species in China[44]. Additionally, as an international megacity, Shanghai is known for its vibrant nighttime activities and seriously jeopardized by light pollution, making it a typical area for studying the impacts of ALAN on urban birds.

2.3 Data Sources and Processing

2.3.1 Birding Data and Processing

The birding data used in this study was sourced from China Bird Report, which has recorded a total of 1,399 species in *A Checklist on the Classification and Distribution of the Birds of China (Fourth Edition)* from May 2014 to November 2024, accounting for about 93% of the country's bird species and 16% of the world's bird species②[45]. The study adopted 606,922 birding records within the study area from January 1, 2017 to December 31, 2023, and each record included information such as bird species name, amount of observed birds, observation coordinates, and observation time. After eliminating duplicate records of the same bird species observed at the same location and the same time, and manually removing obviously inaccurate data, 122,077 birding records were obtained from 3,253 observation sites, covering 500 species and a total of 391,017 recorded birds (Table 1).

2.3.2 Target Bird Species Selection

This study selected the top 10 most frequently observed bird species within the study area as the target species, including *Passer montanus*, *Pycnonotus sinensis*, *Spilopelia chinensis*, *Turdus mandarinus*, *Acridotheres cristatellus*, *Egretta garzetta*, *Sinosuthora webbiana*, *Spodiopsar cineraceus*, *Nycticorax nycticorax*, and *Pica*

① Data source: official website of the Shanghai Municipal People's Government.
② Data source: official website of China Bird Report.

Table 1: Statistics of birding data from China Bird Report

Year	Amount of all-day birding records	Amount and percentage of night birding records	Amount of bird species all-day observed	Amount and percentage of bird species observed at night
2017	2,131	37 (1.74%)	294	24 (8.16%)
2018	2,935	326 (11.11%)	339	84 (24.78%)
2019	2,439	21 (0.86%)	325	21 (6.46%)
2020	8,434	571 (6.77%)	372	203 (54.57%)
2021	19,530	1,725 (8.83%)	405	300 (74.07%)
2022	21,688	1,683 (7.76%)	376	250 (66.49%)
2023	64,920	3,385 (5.21%)	453	333 (73.51%)
Total	**122,077**	**7,748 (6.35%)**	**500**	**383 (76.60%)**

pica. These 10 generalized species have a wide range of ecological niches and strong adaptability, and are representative for studying the impacts of ALAN (Table 2).

2.3.3 ALAN Remote Sensing Data and Processing

The ALAN remote sensing data were obtained from LuoJia1-01 satellite launched by Wuhan University, with a spatial resolution of 130 m. Radiometric calibration of the remote sensing images was performed using the equation officially provided, and the grayscale values were converted into value of irradiance using the following equation:

$$L = DN^{3/2} \times 10^{-10}, \quad (1)$$

where L is the value of irradiance and DN is the grayscale value of the original luminous image.

After this processing, the magnitude of irradiance was unified with the VIIRS satellite data by using the following equation:

$$L' = L \times \omega \times 10^{5}, \quad (2)$$

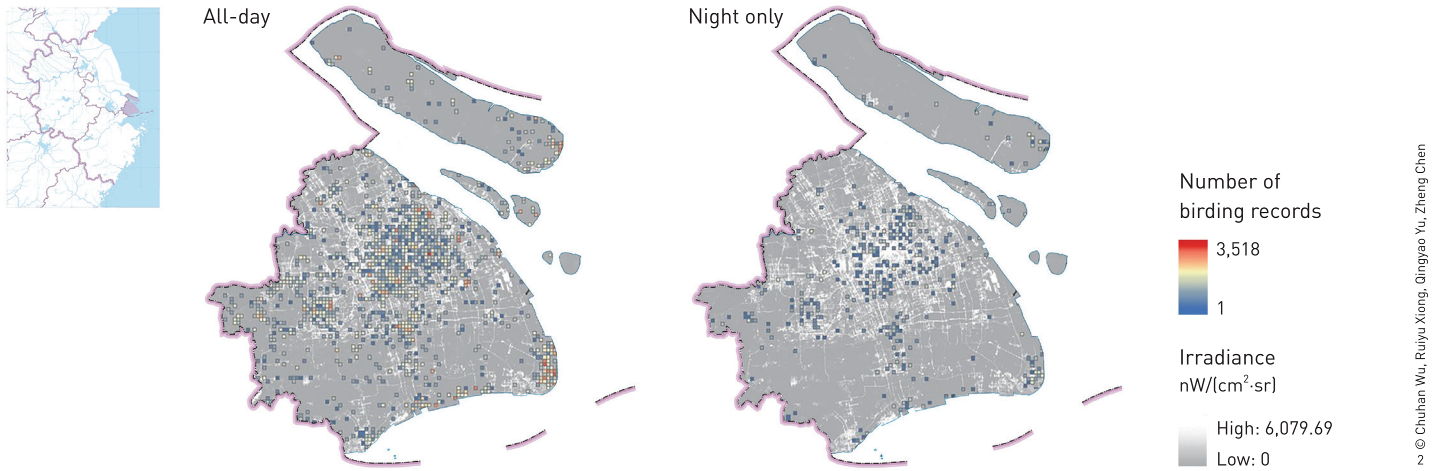
where ω is the bandwidth ranging (460 ~ 980 nm), here set to 520 nm; L' is the irradiance after unit conversion in nW/(cm^2·sr). The remote sensing images of the study area were clipped by the mask tool of GIS 10.2 to obtain the nighttime light data at 130-meter resolution (Fig. 1).

Table 2: Statistics of the target bird species

Species	Order	Family	Observed times	Observed quantity
Passer montanus	*Passeriformes*	*Passeridae*	2,703	18,647
Pycnonotus sinensis	*Passeriformes*	*Pycnonotidae*	3,002	17,136
Spilopelia chinensis	*Columbiformes*	*Columbidae*	3,197	15,536
Turdus mandarinus	*Passeriformes*	*Turdidae*	2,938	12,697
Acridotheres cristatellus	*Passeriformes*	*Sturnidae*	2,343	9,674
Egretta garzetta	*Pelecaniformes*	*Ardeidae*	2,553	9,233
Sinosuthora webbiana	*Passeriformes*	*Paradoxornithidae*	1,698	8,506
Spodiopsar cineraceus	*Passeriformes*	*Sturnidae*	1,572	8,054
Nycticorax nycticorax	*Pelecaniformes*	*Ardeidae*	2,087	6,977
Pica pica	*Passeriformes*	*Corvidae*	2,386	6,879

NOTE
Source of the bird species names: Ref. [45].

1. An illumination irradiance map of the study area.



2. The spatial distribution of birding records within the study area from the year of 2017 to 2023.

2.3.4 Spatial Distribution Analysis of Birding Records and Irradiance Intervals

To explore the impacts of different illumination irradiance intervals of artificial lighting on the spatial distribution of birds, the birding data and the ALAN data were correlated to obtain the birding records–irradiance intervals map.

First, based on the irradiance classification of light pollution by previous research[46][47], the urban nighttime illumination irradiance was graded into five intervals in this research: dark [0, 0.15), low brightness [0.15, 5), medium brightness [5, 25), high brightness [25, 75), and extreme brightness [75, +∞). Second, the observed species and their amounts from 2017 to 2023 were mapped on 1 km × 1 km grid cells (Fig. 2), to derive the number of grid cells with birding records in each irradiance interval.

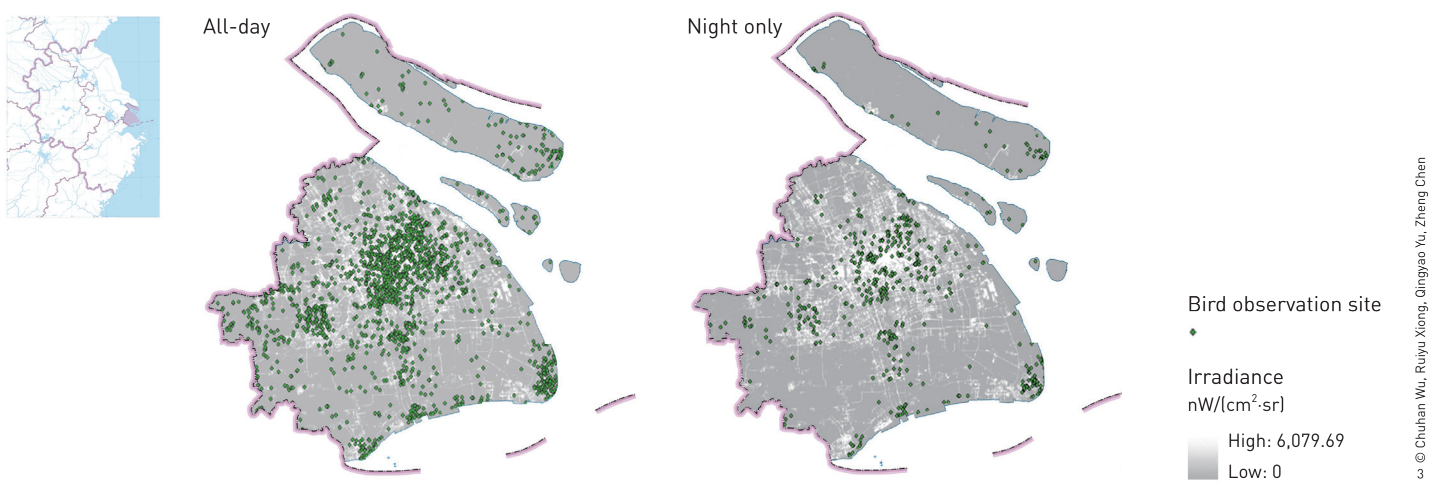
2.3.5 Statistical Analyses

In order to control the influence of other urbanization factors on the results, an ordinary least squares linear regression model was used to fit the relationship between nighttime illumination irradiance and the amount of observed birds. All statistical analyses were done by Stata 17.0 statistical software.

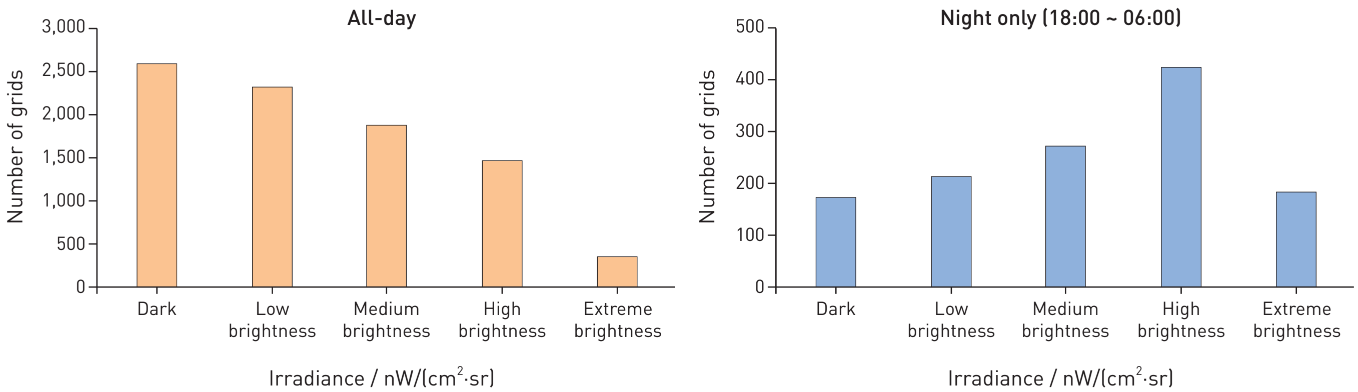
3 Results

3.1 General Characteristics of Birding Records

Generally, the bird observation sites within the study area were mainly concentrated on the central urban districts, with hotspots mainly found around Century Park, Changfeng Park, Zhongshan Park, and parks with good natural conditions (e.g., Houtan Park, Expo Park). In other districts, hotspots were distributed in multiple clusters, especially in Dripping Lake, Chongming Dongtan Wetland, Chenshan Botanical Garden, and other areas with favorable ecological conditions and sound birding resources (Fig. 3). At night, the amount of observation sites decreased significantly, with less concentration, mainly clustered around the city center and Dripping Lake.



3. The spatial distribution of observation sites within the study area from the year of 2017 to 2023.



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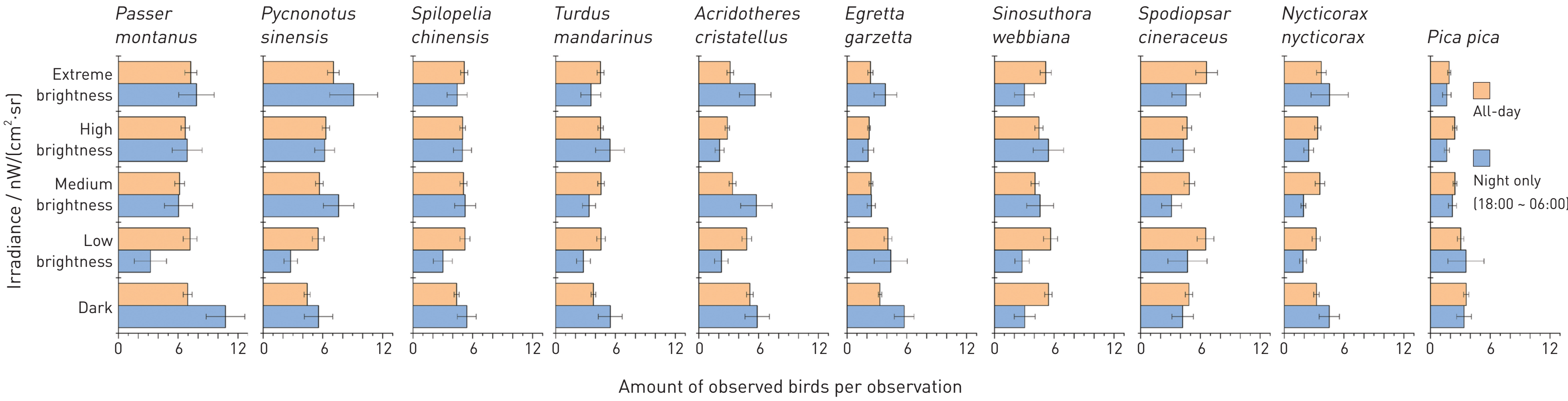
4. Statistics of grid cell amounts with birding records.
5. Average amounts of observed birds across different irradiance intervals. The length of the bars represents the mean number of all observed birds of a given species in a given irradiance interval (calculated by dividing the total number of observation counts by the number of observation sites).



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The spatial distribution statistics of grid cells with birding records in the study area (Fig. 4) showed that there were more birding records in the dark interval throughout the day, whereas the nighttime birding records were mainly found in the high brightness interval. Although there is a bias, citizen science data are still robust considering that there were sufficient samples across all intervals and the smallest intervals of data, i.e., dark and extreme brightness intervals, were of more than 100 grid cells.

3.2 Relationship Between the Amount of Observed Birds and Illumination Irradiance

The study statistically analyzed the observed amounts of 10 target bird species in single observations across the illumination irradiance intervals (Fig. 5). The minor error bars reflected a sound robustness and reliability of the results. The results showed that the impacts of illumination irradiance on different bird species vary and can be summarized into three distribution patterns.

1) Decreasing distribution: the amounts of observed birds of *Egretta garzetta* and *Pica pica* were highest in the dark interval and tended to decrease as illumination irradiance increases, implying that these species may be more sensitive to nighttime light intensity.

2) Multimodal distribution: the number of observations, in addition to being higher in the dark interval, showed clustering in other irradiance intervals, forming bimodal or trimodal distributions, such as *Passer montanus*, *Pycnonotus sinensis*, *Acridotheres cristatellus*, *Nycticorax nycticorax*, and *Turdus mandarinus*. Specially, *Passer montanus* and *Nycticorax nycticorax* witnessed peaks in the dark and extreme brightness intervals, *Turdus mandarinus* saw peaks in the dark and high brightness intervals, while *Pycnonotus sinensis* and *Acridotheres cristatellus* formed peaks in the dark, medium brightness, and extreme brightness intervals. A possible explanation is that urbanization may have led to the concentration of bird populations[48], and these bird species are more tolerant to urban ALAN environments. The light pollution in cities may have altered the nocturnal behaviors of these bird species, which partly explains the rapid growth of *Nycticorax nycticorax* populations along the Huangpu River and Suzhou Creek in Shanghai in recent years[49].

3) Balanced distribution: the numbers of observations of

species of *Spilopelia chinensis*, *Spodiopsar cineraceus*, and *Sinosuthora webbiana* were roughly even or with minor fluctuation between irradiance intervals. This suggests that these birds may have a strong adaptability, enabling them to survive in a variety of urban ALAN environments. *Spilopelia chinensis* and *Spodiopsar cineraceus* saw a more obviously even distribution across the illumination irradiance intervals, without significant differences between the brightest and darkest intervals; *Sinosuthora webbiana* showed a similarly balanced distribution, with a slight concentration in the medium and high brightness intervals.

Additionally, among the three distribution patterns, most species were notably distributed in the dark interval, i.e., 0 ~ 0.15 nW/(cm^2·sr), indicating that the bird species may prefer to inhabit and be active in areas with lower nighttime light intensity.

Table 3: Linear regression analysis between the amount of birding records and irradiance intervals

Species	Average irradiance of observation sites/ nW/(cm^2·sr)	Amount of night birding records	Amount of observed birds at night	β	p
Passer montanus	236.81	212	1,643	−0.095	0.167
Pycnonotus sinensis	229.73	198	1,284	0.119	0.095
Spilopelia chinensis	170.53	206	1,003	−0.026	0.711
Turdus mandarinus	103.61	212	932	−0.055	0.427
Acridotheres cristatellus	150.24	162	738	−0.001	0.990
Egretta garzetta	38.40	295	1,356	−0.143	0.014*
Sinosuthora webbiana	34.87	104	585	0.101	0.307
Spodiopsar cineraceus	260.32	103	424	0.005	0.960
Nycticorax nycticorax	56.68	172	523	−0.069	0.371
Pica pica	14.00	146	495	−0.202	0.014*

NOTE
* means $p < 0.05$.

3.3 Correlation Analysis Between the Amount of Observed Birds and Illumination Irradiance

To further examine the impact degrees of ALAN on the target bird species, a correlation analysis between the amount of observed birds and illumination irradiance was conducted. The results verified that there was a significant negative correlation between the illumination irradiance and the amount of observed birds of *Egretta garzetta* ($\beta = -0.143$, $p < 0.05$) and *Pica pica* ($\beta = -0.202$, $p < 0.05$) in the decreasing distribution pattern, whereas the numbers of the species in the multimodal or balanced distribution patterns were not significantly and linearly correlated with illumination irradiance (Table 3). In addition to the possible impact of urbanization on bird distribution, another reason could be the bias in citizen science data, as most observation sites are concentrated in urban areas with higher illumination irradiance[50].

4 Summary and Outlook

4.1 Conclusions and Discussion

The study focuses on the impacts of nighttime light pollution in Shanghai, using ALAN remote sensing data and citizen science data (Shanghai's birding records from China Bird Report) and selecting 10 common bird species, to examine how bird species distribution was impacted by varied illumination intervals at night. It found that there were disparities in the impact of ALAN radiance on different bird species, and the amounts of birds showed three patterns of distributions—decreasing, multimodal, and balanced. The following main findings were identified.

1) The average observed amount of urban bird species was not even in different illumination irradiance intervals. Most urban birds studied in this research might prefer darker environments—in the irradiance interval of 0 ~ 0.15 nW/(cm^2·sr)—while species such as *Passer montanus* and *Nycticorax nycticorax* showed large distributions on irradiance intervals of 75 nW/(cm^2·sr) and above. In addition, species such as *Spilopelia chinensis* were less impacted by the nighttime light intensity and were more evenly distributed. This may be because ALAN provides a suitable urban foraging environment for some bird species at night, while areas with higher illumination irradiance are more convenient for bird observation.

2) ALAN may reduce bird activities of some species. The average observed amounts of *Egretta garzetta* and *Pica pica* showed significant negative correlations with illumination irradiance,

while the rest of the target bird species showing multimodal or balanced distribution across the illumination irradiance intervals. This may imply that these bird species are better adapted to urban environments[51][52] and are not averse to being in brighter areas at night.

From the perspective of promoting bird-friendly urban environments, city management should pay attention to reduce the illumination irradiance in urban parks, nature reserves, etc. where birds congregate, so as to balance the needs of human recreational activities and biodiversity conservation.

4.2 Outlook and Application Prospects

Reducing light pollution, coordinating the human–bird harmony in cities, and building dark-night friendly environment all respond to the requirements for the construction of ecologically livable and beautiful cities[53]. From 2000 to 2020, ecological restoration measures have led to the growth of vegetation coverage in historical downtowns in the Yangtze River Delta region[54], providing more habitats for birds in the city. This study has shown that the general lighting level in Shanghai is relatively intensive, and birds are mainly concentrated in green spaces like urban parks and ecological reserves, where extra attention should be paid to reducing nighttime lighting intensity and limiting citizens' recreational activities at night. In addition to restrictions on lighting and activity management of urban parks, there is also a need to reduce lighting intensity in urban residential areas, where a large number of wild lives are largely affected by ALAN. Minimizing the intensity of artificial lighting can promote the balance of urban ecosystems.

This study innovatively adopted citizen science data as the source of bird distribution information. Compared with the traditional grid analysis, such data may have "systematic biases" in spatial and temporal distribution[55]; at the spatial level, the data mostly represented the areas with high population density or convenient transportation at the temporal level, it shows a pattern of more observation activities on weekends than on weekdays, and more during the day than at night—although birding records in low-illumination environments during late-night hours are relatively scarce, the focus of this study on ALAN hours ensures a sustainable amount of data. Notably, a nighttime bird sound collection project initiated by the Kunming Bird Research Institution (the operation team of China Bird Report) in May 2024 could complement the birding data in extremely dark environments③. To further enhance the reliability of citizen science data, future studies may explore strategies such as implementing the minimum magnitude testing and constructing distribution models to enhance data robustness[33][36].

This research also sees limitations. First, the remote sensing data may deviate from actual ground-level lighting conditions due to factors such as vegetation shading, though remote sensing data offer advantages in ecological validity and breadth, providing a broader perspective on bird distributions, compared with fine-grained laboratory studies. Second, the number of single bird species was used as the main variable in this study; future studies can incorporate more robust indicators such as biodiversity metrics to improve credibility. In addition, this research only preliminarily discusses the impacts of ALAN on the amount of observed birds; other environmental factors affecting bird activities, such as land use types and vegetation patterns, can be considered in future studies.

③ Information source: official WeChat Account of Kunming Vermilion Bird Research Institute.

Competing interests | The authors declare that they have no competing interests.

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基于公民科学家数据的夜间人工照明对上海市鸟类分布的影响研究

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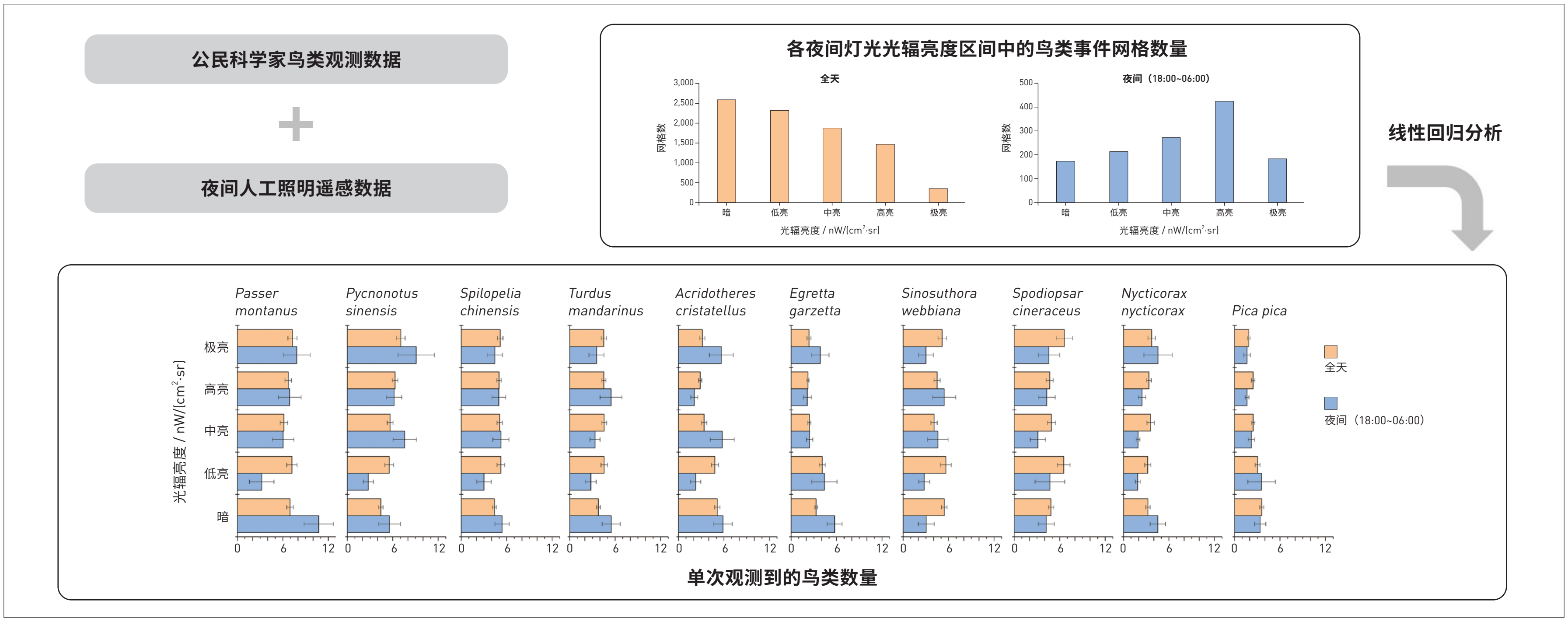
图文摘要



摘要

夜间人工照明是维持城市夜间功能的重要基础设施，也是衡量城市活力和经济发展的重要指标。但夜间人工照明的增加也正广泛影响着城市生物和居民的整体健康。公民科学家数据具有样本量大、时空数据完整等优势，在生态调查和相关研究中具有良好的应用前景。在此背景下，本文以上海市为例，利用公民科学家数据和遥感数据，探索了夜间人工照明强度对城区鸟类分布的影响情况。研究使用中国观鸟记录中心2017～2023年在上海市的鸟类观测数据，并从中选择了10种广泛分布的代表鸟种进行分析。对比夜间人工照明遥感数据，研究发现夜间人工照明光辐亮度对不同鸟种的影响存在差异，观测鸟只数量随着光辐亮度的增强呈现出递减、多峰、均衡三种分布形态。其中，大部分鸟种分布于0～0.15nW/(cm^2·sr)的低光辐亮度区间内，而夜鹭（*Nycticorax nycticorax*）、麻雀（*Passer montanus*）等少数鸟

种在75nW/(cm^2·sr)及以上的高亮度区间也出现高聚集情况。本研究初步识别了夜间人工照明强度与城区鸟类分布的关系，提出了鸟类可能偏好的光辐亮度范围，为城市降低光污染、营造暗夜友好城市环境提供了研究基础和策略方向。

关键词

城区鸟类；夜间人工照明；鸟类分布；光辐亮度；光污染影响；公民科学家数据

文章亮点

- 夜间人工照明可能影响城区鸟类分布，不同鸟种的观测数量随着光辐亮度的增强呈现出递减、多峰和均衡三种分布形态
- 大部分鸟种倾向在低光辐亮度区域聚集，但少数也能适应高光辐亮度
- 公民科学家数据有样本大、时空数据更完整等特点，能够作为系统性鸟类调查的有效补充

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1 研究背景

景观照明既有基础照明作用，又兼具环境美化、艺术装饰等多重功能。但同时，高强度的人工照明造成的光污染会对野生动植物产生严重影响[1]~[3]。例如，美国纽约的“纪念之光”是纪念“9·11事件”的标志性景观照明装置，然而据报道，每年约有16万只鸟因其死亡[4]。

鸟类是受光污染影响最为严重的物种之一[5]。夜间人工照明会影响鸟类光周期感知，扰乱昼夜节律、行为规律、激素分泌，改变其季节性繁殖、免疫功能和代谢率等[6][7]，对鸟类健康造成损害[8]，甚至影响城市留鸟的存活率[9]~[11]。夜行性鸟类，尤其是飞行定向的候鸟，视网膜中用于感知光强的视杆细胞占比较多[12][13]，对光的增强更为敏感[14][15]。研究表明，欧亚大山雀（*Parus major*）在1.6lux的光照环境下会改变睡眠行为[16]，而暴露在白光下也会使其免疫功能下降，更易感染疟疾[17]；暴露在0.3lux光照环境中的欧乌鸫（*Turdus Merula*）褪黑素的释放量会减少[18]；暴露在模拟城市照明环境中的麻雀（*Passer montanus*），其褪黑素水平及肠道菌群的物种多样性和丰富度均会下降[19]。

基于遥感数据的生物视角夜间光环境研究主要聚焦夜间光污染区域的识别[20][21]，以及夜间人工照明与迁徙候鸟之间的关联[22][23]。有研究表明，夜间光污染显著影响城区鸟类多样性，鸟类多样性会随光辐亮度的增加而下降[24]。光污染对不同鸟种的影响程度也存在区别，食虫和杂食性鸟类受到的负面影响较为显著，而食肉鸟类几乎不受影响[25]。以森林为主要栖息地的鸟类，其密度受夜间人工照明影响显著，而在农田环境中生存的鸟类一定程度上可以忍受人工照明[26]。然而，现有研究对于光污染之于不同鸟种分布的影响认识不够全面：较少提及在城市尺度下影响鸟类分布的光辐亮度关键阈值[27]，同一区域鸟种的视觉光谱敏感度也不明晰[23]；研究中采用的数据大多空间精度较低（分辨率大于500m），如来自NPP VIIRS、DMSP/OLS等的夜光遥感数据[20][25][26]，对于城市夜光管理的指导意义较弱。

当前，许多国家和地区已采取措施降低光污染对鸟类的危害。自2001年起，国际暗夜协会已经认证了200多个“世界暗夜地点”，它们兼具优质的户外照明、有效的光污染治理政策，以及持续的管理实践[28]；2019年，纽约市要求所有新建筑采用“鸟类友好型”玻璃，以减少建筑碰撞伤亡[29]；2022年，该市又出台地标光的相关法案，要求非必要的室外照明灯须在夜间11点后关闭或进行遮盖[30]。2022年，我国首部纳入光污染治理的地方性环境保护法规《上海市环境保护条例》正式实施，规定不符合照明限值等要求的道路照明、景观照明及户外广告、户外招牌等设施应当及时调整，但并未提及光污染与生物保护的关系[31]。

不同于传统的实地调查[32]和GPS跟踪[33]等高时间成本、低数量级的鸟类信息收集方法，公民科学家数据提供了一种低成本的大范围数据获取途径。“公民科学”（citizen science）一般是指非科研领域的公民受邀或自愿参与科学数据的收集、整理和分析等，以解决科学问题[34]。公民科学家数据为大型时空尺度下描述鸟类的丰度、分布和功能组成并验证假设提供了新的可能性，在揭示地理现象的空间和时间动态方面具有巨大潜力[35][36]，年均鸟类记录数量达百万级。其数据虽然存在时空间分布偏差，但研究表明，通过科学的处理方法，公民科学家数据可以作为高信度的数据来源：一方面，利用大数据建模分析参与者检测和识别鸟类能力的个体差异，能够排除高风险参与者[37]；另一方面，公民科学家数据累积到一定量级即能够达到研究有效水平[38]。另外，也可利用物种分

布模型提升公民科学家数据均度[37]。观鸟爱好者可在特定平台上传观测到的鸟类种类、地点等信息，eBird、中国观鸟记录、Movebank等公民科学家数据库目前已被广泛使用[38]。

本研究创新性地结合夜间人工照明遥感数据和公民科学家数据，以上海市城区为例，探究夜间人工照明水平与鸟类栖息活动的关系，以助力城市暗夜友好环境建设。本研究旨在回答以下研究问题：夜间人工照明作为城市夜间活动重要支持[39][40]，可能对城市鸟类分布产生怎样的影响？是否存在鸟类偏好的光辐亮度阈值？城市管理应该如何协调夜间人工照明和鸟类保护的关系？

2 研究方法

2.1 夜间的定义

夜间一般指从黄昏到黎明，太阳低于地平线的时段（即太阳方位角–6° 以下）[41]。依据城市照明的工作时间，本研究中的“夜间”指18:00到次日06:00，覆盖了大部分鸟类活动较为频繁的晨昏时段[42]，且与城市夜间开启照明的时段基本相同。

2.2 研究地点选择

本研究选择上海市域为研究范围，总面积6 340.5km^{2}①。上海市是东亚—澳大利西亚候鸟迁徙路线的重要中转站[43]，截至2022年底，研究范围内已累计记录到野生鸟类519种，涵盖22目79科，占全国鸟种总数约三分之一[44]。同时，上海市作为一座国际性特大城市，夜间活动丰富，光污染严重，因此探讨上海市城区鸟类受夜间人工照明的影响具有重要的研究意义。

2.3 数据来源及处理

2.3.1 鸟类观测数据及处理

本研究使用的鸟类观测数据来源于中国观鸟记录中心。自2014年5月至2024年11月，中国观鸟记录中心共观测到《中国鸟类分类与分布名录（第四版）》中的记载鸟类1 399种，约占全国鸟种的93%、全球鸟种的16%②[45]。本研究以中国观鸟记录中心自2017年1月1日至2023年12月31日在研究区域内的606 922条观鸟记录作为数据来源，每条记录中包括物种名称、数量、观测坐标、观测时间等信息。通过剔除同一地点、同一时间观测到的同一鸟种的重复数据，并对明显不准确的观测记录数据进行手动剔除，研究最终获得来自3 253个观测点的122 077条观测记录，包含500种鸟类，总计391 017只次（表1）。

① 数据来源：上海市人民政府官方网站。
② 数据来源：中国观鸟记录中心官方网站。

表 1：研究鸟类观测数据统计信息

年份	全天观测记录条数	夜间观测记录条数及占比	全天观测鸟种数	夜间观测鸟种数及占比
2017	2 131	37（1.74%）	294	24（8.16%）
2018	2 935	326（11.11%）	339	84（24.78%）
2019	2 439	21（0.86%）	325	21（6.46%）
2020	8 434	571（6.77%）	372	203（54.57%）
2021	19 530	1 725（8.83%）	405	300（74.07%）
2022	21 688	1 683（7.76%）	376	250（66.49%）
2023	64 920	3 385（5.21%）	453	333（73.51%）
总数	**122 077**	**7 748（6.35%）**	**500**	**383（76.60%）**

2.3.2 目标鸟种选择

研究选取观测数量排名前10的鸟种作为目标鸟种，分别为：麻雀（*Passer montanus*）、白头鹎（*Pycnonotus sinensis*）、珠颈斑鸠（*Spilopelia chinensis*）、乌鸫（*Turdus mandarinus*）、八哥（*Acridotheres cristatellus*）、白鹭（*Egretta garzetta*）、棕头鸦雀（*Sinosuthora webbiana*）、灰椋鸟（*Spodiopsar cineraceus*）、夜鹭（*Nycticorax nycticorax*）和喜鹊（*Pica pica*）。这10种泛化种鸟类（食性和栖息地广泛的物种）具有广泛的生态位和较强的适应能力，它们受夜间人工照明影响的情况具有一定代表性，故将其作为目标鸟种进行研究（表2）。

2.3.3 夜间人工照明遥感数据及处理

夜间人工照明遥感数据来源于武汉大学发射的珞珈一号（LJ1–01）卫星，空间分辨率为130m。基于官网提供的辐射定标方程对LJ1–01遥感影像进行辐射定标，将灰度值转化为光辐亮度值:

$$L = DN^{3/2} \times 10^{-10}, \quad (1)$$

式中，L为校正后的光辐亮度值，DN为原始夜光影像的灰度值。

进行上述处理后，为将光辐亮度的量纲与VIIRS卫星数据统一，通过

表 2：目标鸟种统计数据

目标鸟种	拉丁名	目	科	观测次数	数量
麻雀	*Passer montanus*	雀形目	雀科	2 703	18 647
白头鹎	*Pycnonotus sinensis*	雀形目	鹎科	3 002	17 136
珠颈斑鸠	*Spilopelia chinensis*	鸽形目	鸠鸽科	3 197	15 536
乌鸫	*Turdus mandarinus*	雀形目	鸫科	2 938	12 697
八哥	*Acridotheres cristatellus*	雀形目	椋鸟科	2 343	9 674
白鹭	*Egretta garzetta*	鹈形目	鹭科	2 553	9 233
棕头鸦雀	*Sinosuthora webbiana*	雀形目	鸦雀科	1 698	8 506
灰椋鸟	*Spodiopsar cineraceus*	雀形目	椋鸟科	1 572	8 054
夜鹭	*Nycticorax nycticorax*	鹈形目	鹭科	2 087	6 977
喜鹊	*Pica pica*	雀形目	鸦科	2 386	6 879

注
鸟类命名来源：参考文献 [51]。

以下公式转化：

$$L' = L \times \omega \times 10^5, \quad (2)$$

式中，ω 为带宽，范围为460～980nm，将 ω 取为520nm；L' 为统一量纲后的光辐亮度，单位为nW/(cm^2·sr)。利用GIS 10.2的掩膜工具对处理后的夜光影像数据中本研究范围所覆盖的部分进行裁切，获得LJ1-01的130m精度夜间灯光数据（图1）。

2.3.4 鸟类—光辐亮度区间空间分布分析

为探究不同光辐亮度区间对鸟类的影响，研究将鸟类观测数据和夜间人工照明遥感数据进行空间关联，以获取鸟类—光辐亮度区间空间分布地图。

首先，参考既有研究中对于光污染辐射量的划分[46][47]，研究对城市夜间灯光光辐亮度进行梯度分级，分为暗［0，0.15）、低亮［0.15，5）、中亮［5，25）、高亮［25，75）和极亮［75，+∞）5个区间，单位为nW/(cm^2·sr)。其次，将2017～2023年间累计观测到的鸟类的种类和数量（以下统称“鸟类事件”）映射在1km×1km的单元网格上（图2），从而统计出各光辐亮度区间内观测到鸟类事件的单元网格数量。最终形成的空间地图可反映各光辐亮度区间的鸟类分布情况。

2.3.5 统计分析

为排除其他城市环境因子对研究结果的影响，研究采用基于普通最小二乘法的线性回归模型对夜间光辐亮度与鸟类观测数量关系进行拟合分析，旨在直观展现夜间光辐亮度与各种鸟类观测数量的关系。以上统计分析均在Stata 17.0统计软件中完成。

3 研究结果

3.1 鸟类观测结果总体特征

综合全天观测数据，研究范围内的鸟类观测点主要集中于光辐亮度较高的城市中心区域——热点区域包括世纪公园、长风公园、中山公园周边区域，以及后滩公园、世博公园等自然条件良好的公园绿地——其他区域则呈多点聚集分布，例如滴水湖、崇明东滩湿地、辰山植物园等自然生态条件优越、观鸟资源丰富的区域（图3）。夜间观测点明显减少，集中性较弱，主要分布在市中心和滴水湖区域。

根据研究区域内单元网格鸟类事件观测空间分布结果（图4），发现全天中鸟类事件主要集中于暗区间，而夜间主要集中在高亮区间。虽然公民科学家数据存在偏倚，但考虑到该数据在各区间都有足够样本，且数据量最小的区间（夜间暗区间和极亮区间）也超过100个网格，所以可认为数据较为稳健。

3.2 鸟类数量和光辐亮度的关系

研究统计了10个目标鸟种单次观测的平均观测数量（图5），较小的误差棒说明研究结果具有较好的稳健性。结果显示，不同鸟种的观测数量随着光辐亮度的增强呈现出三种分布形态：

1）递减分布：在暗区间的观测数量最高，并随光辐亮度的增强大体呈下降趋势，如白鹭和喜鹊，这可能意味着这些物种对高亮度环境更为敏感。

2）多峰分布：观测数量除了在暗区间较高外，在其他光辐亮度区间呈现双峰或三峰聚集分布，如麻雀、白头鹎、八哥、夜鹭和乌鸫。其

中，麻雀和夜鹭在暗区间和极亮区间出现峰值，乌鸫在暗和高亮区间形成峰值，而白头鹎和八哥则在暗、中亮和极亮区间出现峰值。这可能是因为城市化导致了鸟类种群的集中[48]，且这些鸟种对城市环境的容忍度较高，已适应夜间人工照明环境，并能在照明较强的区域进行觅食等行为。另外，城市光污染也可能改变了这些鸟种的夜间活动范围，这也可以在一定程度上解释夜鹭种群数量近年来在“一江一河”（即黄浦江和苏州河）地区快速增长的现象[49]。

3）均衡分布：观测数量在不同亮度区间内的分布基本持平或波动幅度较小，如珠颈斑鸠、灰椋鸟和棕头鸦雀。这表明这些鸟类可能具有较强的适应性，能够在多种亮度环境中生存。其中，珠颈斑鸠和灰椋鸟呈均衡分布，在最亮或最暗区间均无显著差异；棕头鸦雀的分布较为均衡，稍集中于中高亮度区间。

这三种分布形态的共同集聚区集中在0～0.15nW/(cm^2·sr)光辐亮度的暗区域，这表明本研究所选的目标鸟种可能更偏好在光辐亮度较低的空间环境中栖息活动。

3.3 鸟类观测数量和光辐亮度的相关性分析

为了验证夜间人工照明对目标鸟种分布的影响程度，本研究进行了鸟类观测数量和光辐亮度的相关性分析。结果显示，递减分布中白鹭（β=–0.143，p<0.05）和喜鹊（β=–0.202，p<0.05）的观测数量与光辐亮度显著负相关；而多峰分布及均衡分布的鸟种，其数量和光辐亮度并不存在显著线性关系（表3）。除了城市化对鸟类分布的可能影响外，另一可能原因是公民科学家数据本身采样存在偏倚，样本更倾向于光辐亮度较高的城区[50]。

表 3：鸟类观测数量和光辐亮度的线性回归分析

目标鸟种	观测点平均光辐亮度／nW/(cm^2·sr)	夜间观测记录条数	夜间观测鸟只数量	β	p
麻雀	236.81	212	1 643	− 0.095	0.167
白头鹎	229.73	198	1 284	0.119	0.095
珠颈斑鸠	170.53	206	1 003	− 0.026	0.711
乌鸫	103.61	212	932	− 0.055	0.427
八哥	150.24	162	738	− 0.001	0.990
白鹭	38.40	295	1 356	− 0.143	0.014*
棕头鸦雀	34.87	104	585	0.101	0.307
灰椋鸟	260.32	103	424	0.005	0.960
夜鹭	56.68	172	523	− 0.069	0.371
喜鹊	14.00	146	495	− 0.202	0.014*

注
* 表示 p < 0.05。

4 总结与展望

4.1 结论与讨论

研究关注上海市夜间人工照明对城区鸟类的影响，基于夜间灯光遥感数据与公民科学家数据（中国观鸟记录中心2017～2023年上海市数据），选取了10个常见鸟种进行分析。从夜间鸟类分布受照明影响的角度入手，研究发现，夜间人工照明光辐亮度对不同鸟类的影响存在差异，鸟类数量随光辐亮度增加呈现递减、多峰、均衡三种分布形态，进一步分析显示：

1）不同夜间光辐亮度区间内，城区鸟类平均观测数量分布不均衡。大部分鸟种聚集分布在0～0.15nW/(cm^2·sr)的低光辐亮度区间内，但也有部分鸟种偏好中等亮度或更亮的环境，如以麻雀、夜鹭为代表的鸟种在75nW/(cm^2·sr)及以上的高亮度区间也出现高聚集情况。此外，珠颈斑鸠等鸟种受亮度影响较小，分布较为均衡。这可能是因为城市夜间人工照明为某些鸟类创造了合适的觅食条件，而且在光线较亮的区域，鸟类也更易被观察到。

2）夜间人工照明可能会抑制部分鸟类活动。白鹭、喜鹊的观测数量与光辐亮度呈显著负相关，而其余鸟种沿光辐亮度梯度呈现多峰或均衡分布。这可能意味着，这些鸟种能更好地适应城市环境[51][52]，对夜间在较亮地区活动并不排斥。从暗夜友好视角出发，城市管理应着重降低鸟类聚集分布的城市公园绿地、自然保护区等区域的夜间人工照明强度，平衡人类游憩活动和鸟类保护的需求。

4.2 展望与应用前景

降低光污染，协调鸟类和人类在城市中和谐共生，建设暗夜友好环境，是对生态宜居的美丽城市建设要求的回应[53]。2000～2020年间，长江三角洲地区城市老城区植被覆盖总体呈返绿趋势[54]，为鸟类在城市中提供了更多的栖息地。本研究表明，上海市普遍照明水平较高，而鸟类主要集聚于城市公园绿地、自然保护区等区域，这些地区需要格外注意

降低夜间人工照明强度，并限制市民的夜间游憩活动。除了对公园绿地的照明及活动管理的限制外，城市居住区内大量野生动物也受到夜间人工照明强度的严重影响，减少照明强度能够更好地促进城市内生态系统的平衡。

本研究创新性地使用了公民科学家数据作为鸟类分布数据的来源，相较于传统的实地网络调查数据，此类数据在时空分布上可能存在“系统性偏差”[55]：空间层面，数据多聚焦于人口密度高或交通便利的区域；时间层面则呈现出周末观测活跃度高于工作日、白天活跃度高于夜间的特征。尽管观测者在深夜低光辐亮度环境下的观测活动相对稀少，但本研究主要聚焦的有夜间人工照明的晨昏时段仍有大量数据记录。值得注意的是，2024年5月昆明市朱雀鸟类研究所（负责中国观鸟记录中心数据库建设维护的团队）发起的夜间鸟声采集活动，可作为极暗环境下观鸟数据的补充③。为增强公民科学家数据的可靠性，未来研究可通过实施最低量级检验、构建分布模型等策略增强数据稳健性[33][36]，进一步探索鸟类分布与环境要素的关系。

本研究存在以下不足之处。研究采用的遥感数据可能由于植被遮挡等情况与地面光照环境存在偏差，但相较于实验室环境下的精细研究，遥感数据提供的宏观视角在鸟类分布的生态效度与广度上具有优势。本研究以单一鸟种观测数量为主要变量，未来可考虑纳入生物多样性等更稳健的指标。此外，本研究仅初步探讨了夜间人工照明对鸟类观测数量的影响，后续研究可将其他影响鸟类活动的环境因子（如土地利用类型、植被格局等）纳入考量。

③ 信息来源：昆明市朱雀鸟类研究所官方微信公众号。

图 1. 研究范围光辐亮度图。
图 2. 2017 ~ 2023 年，研究范围内鸟类事件数量空间分布。
图 3. 2017 ~ 2023 年，研究范围内鸟类观测点空间分布。
图 4. 2017 ~ 2023 年，各光辐亮度区间单元网格数量统计。
图 5. 不同光辐照度下的观测到的鸟类数量。柱状图的长度代表该光辐亮度区间内，该鸟种所有观测数的平均只次（根据观测总数除以观测点数量计算得出）。