

# Artificial Night Lighting Reduces Firefly (Coleoptera: Lampyridae) Occurrence in Sorocaba, Brazil

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## Abstract

Artificial night lighting is gaining attention as a new type of pollution; however, studies of its impacts are scarce. Fireflies provide good models to investigate its effects on nocturnal wildlife, since they depend on their bioluminescence for reproduction. This study investigated the impact of artificial illumination on firefly activity at the new campus of the Federal University of São Carlos (Sorocaba, Brazil). The flashing activity of different firefly species, especially *Photinus* sp1 (82% of all occurrences), was investigated during 3 years, before and after the installation of multi metal vapor spotlights. Quantitative and qualitative analysis, performed in transects at different distances from the artificial light sources, showed significant negative effects on *Photinus* sp1 occurrence. This study proposes fireflies as potential flagship species and bioindicators for artificial night lighting and for the first time quantifies its effects, providing subsidies for future conservationist legislations regarding photopollution.

## Keywords

Photopollution, Fireflies, Bioindicators, Flagship Species, *Photinus*

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## 1. Introduction

Artificial night lighting has increased globally during the last decades [1], but conversely still receives little attention when compared to other kinds of pollutions [2]-[5]. Although plants and animals, *i.e.* birds, sea turtles, invertebrates and even humans are negatively affected by artificial light [2] [6], its effects have been for long neglected and detailed studies of its impacts are few [7]-[9].

Insects are adapted to natural light regimes and thus are sensitive to light in terms of periodicity [10]-[12], polarization [13]-[16], intensity, source and wavelength [16]-[20]. Among them, nocturnal insects have a highly sensitive visual system [21] and some display superposition compound eyes that are 100 - 1000 times more sensitive than that of apposition eyes (typical of diurnal insects) of the same size [17]. Thus, nocturnal insects can perform during night the same visual tasks as diurnal ones with comparable precision and accuracy [22] [23]. These activities include recognizing and reacting to conspecifics and predators, foraging [11] and navigating using stars [24] [25], moon [15] [26] and even learned visual landmarks [27]-[30]. Therefore, considering their adaptation to night lighting natural regimes, nocturnal insects are prone to be more sensitive to photopollution, being attracted, repelled, disoriented or blinded by artificial night lighting [9]. These and other interferences can subsequently alter behavior, dormancy, migration, activity levels (e.g. pollination, nectaring and bioluminescence), reproductive success, predator-prey balance and survivorship [9] [10] [31] [32], consequently scaling up to alterations on community compositions and beyond (e.g. ecosystem services, balance and stability) [32].

Among the few existing studies of the impacts of photopollution on insects, moths and other Lepidoptera are the most common focus organisms [33]-[36]. Due to photopollution, moths, which are key consumers, prey and pollinators, are suspected to experience declines in diversity and abundance [33] [34]. However, further studies are needed to achieve conclusive evidences. The attraction of Lepidoptera and Coleoptera to artificial light is known [36] for causing behavior and life cycle changes, increased exposure to predators, like birds [37] and bats [38] [39], or even direct mortality [9] [35]. Nevertheless, Van Langevelde and colleagues [34] indicated that larger wavelengths reduced the negative effects of photopollution on moth populations. Similar results were found when lights with shorter wavelengths (the ones emitting UV, high pressure mercury vapor, sodium-xenon and sodium vapor lamps, respectively) attracted more insects in abundance and diversity [31] [40]. Those findings agree with the visual ecology sensitivity to UV (30 - 400 nm) of nocturnal insects [17] [39] [41] and suggest that low pressure sodium lamps (580 - 600 nm) will have less impacts on insects than other lamps [20]. However, the scenario is much more complicated, since nocturnal insects discriminate spectral composition for different purposes and therefore have different sensibilities to light [17] [42].

Among nocturnal insects, fireflies are especially vulnerable to artificial night lighting since they depend on their bioluminescence for reproduction [2]; whereas click beetles and railroad worms use it additionally for defensive purposes [43] [44]. In fireflies, bioluminescence communication evolved to species-specific mating communication systems [44] [45] drawing a complex photoecology scenario. These beetles are active mainly after sunset and during the first hours of the night, since the visualization of the bioluminescent flashes is fundamental for their reproduction [43] [44] [46]-[50]. The beginning of their flashing activity has been shown to be modulated by environmental light intensity [48]. These facts support the hypothesis that firefly populations are negatively and strongly affected by artificial night lighting.

Bioindicators should be sensitive to environmental changes [51]. Fireflies, besides their sensitivity, can be easily spotted at night making them good candidates for environmental artificial night lighting bioindicators. Additionally, fireflies are charismatic (a rare characteristic among insects), making them potential flagship species regarding photopollution. Recent study [52] supports this idea given the strong participation of locals on a conservation project. Moreover, they found correlations between high levels of luminance and the absence of the firefly *Luciola italica* L. [52]. Nevertheless, more detailed quantitative studies are until now missing.

Brazil hosts the largest diversity of luminescent beetles in the world [53]. The southeastern is the most populated, developed and consequently artificially illuminated region and is undergoing continuous expansion. However, the effect of urban sprawl and artificial night lighting on the environment and on fireflies diversity is just starting to be investigated [7] [54]. Consequently, there is an urgent need for studies analyzing the impacts of artificial night lighting on the environment with the aim of providing subsidies for the creation of effective conservationist policies [2] [7]. This study was conducted at the new campus of the Federal University of São Carlos, Brazil (hereafter UFSCar) built in 2008. It is located at a rural area of Sorocaba municipality which is undergoing urban sprawl, providing a good site to investigate the effects of artificial night lighting on firefly occurrence.

## 2. Material and Methods

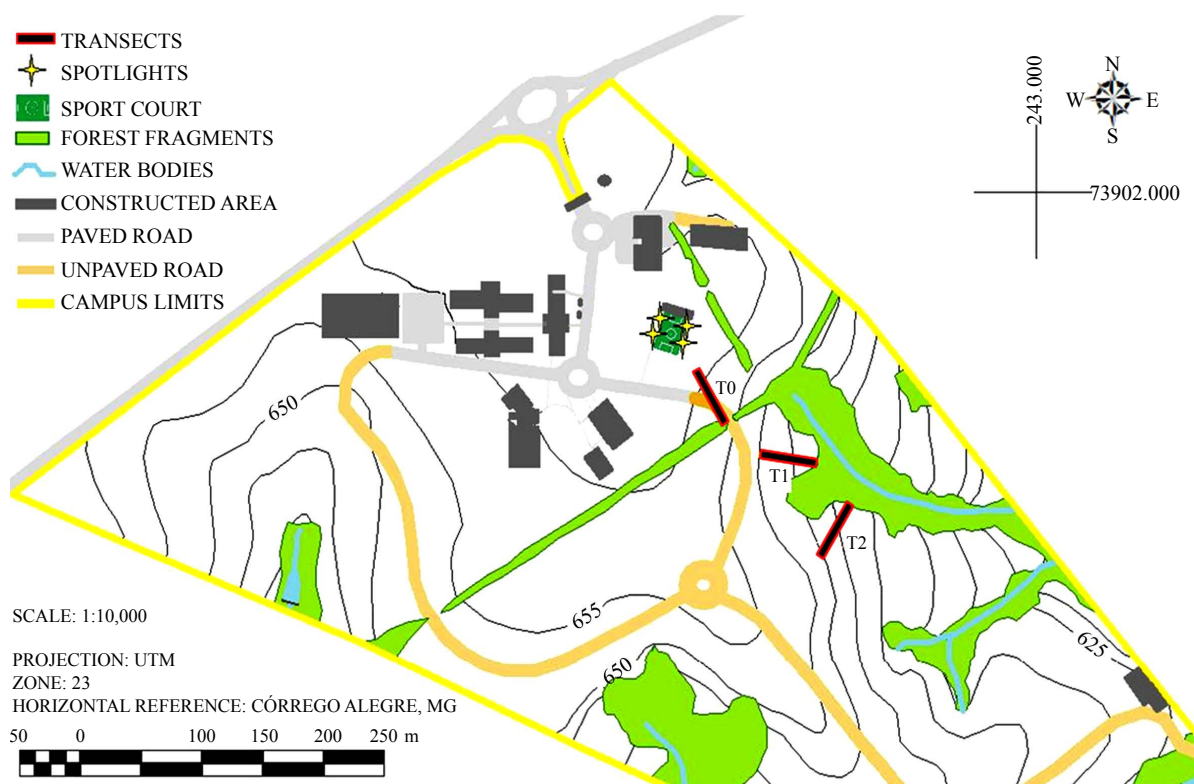
From 2006 to 2007, we catalogued the biodiversity of luminescent beetles in the study area before the installation of the main artificial light sources. From November 2008 to December 2010, we measured the effects of artificial light on firefly diversity and populations, totalizing 82 days of field observations.

### 2.1. Study Area

The UFSCar campus is located in the periphery of Sorocaba municipality in a rural area (**Figure 1**) (23°34'53"S and 47°31'28"W, 666 m above sea level), southeastern Brazil. The region is characterized by hot and humid tropical climate, with an average annual temperature of 21°C, and monthly averages over 20°C between October and April. In the summer and rainy season, the average monthly temperature is 22°C with 200 mm of rainfall. The winter and dry season is from April to October, with droughts from June to September with temperatures below 18°C and 30 mm of precipitation. Local vegetation consists of small fragments (<11 ha) of remnant Atlantic rain forest surrounded by implanted pastures consisting mostly of the introduced grass *Brachiaria* sp., thus characterizing a typically degraded area. The area was used as pasture since the beginning of the 19th century with no history of artificial illumination nor use of pesticides.

### 2.2. Artificial Light Sources

The light sources in the area were: a) sodium vapor lamps along the pavements near the university buildings; b) indoor fluorescent lamps; c) a red light on a water tank (≈300 m from the studied area); d) “skyglow” [2] from the Sorocaba City at Northeast (usually a yellowish-orange glare, depending on atmospheric conditions) and neighborhoods on the west (white) and east (yellow to red); e) four spotlights from a sport court with three multi metal vapor lamps each (model HQI-T 400 W) that was the main source of light near the transects and became operational in August 2009.



**Figure 1.** Study area in 2010, showing the position of the three transects (T0, T1 and T2), spotlights, constructions, vegetation and water bodies.

## 2.3. Transects and Measurements

Three transects of  $50 \times 2$  meters were determined and named T0, T1 and T2 (**Figure 1**). All the transects ended on fragments of semi-deciduous forest in early regeneration state and were walked in 1 min. The positions were chosen for their relationship to the main artificial light source e):  $\approx 60$  m T0,  $\approx 150$  m T1 and  $\approx 280$  m T2. Transects T0 and T1 were directly illuminated by the spotlights of the sport court (**Figure 1**).

Twice a week transects were randomly visited every 10 minutes. Measurements were initiated after the time of sunset and ended after 120 min. 363 transects were scanned when the spotlights were turned on, and 346 when off. The state of the spotlights was totally random and dictated by the usage of the sport court.

For each transect the following parameters were recorded: light intensity; time; quantity and quality of coverage of the sky measured in eighths; temperature; relative humidity; wind; moon phase. The number of flashing individuals (here referred as occurrences) was quantified by counting the meetings during the transect scanning. The recurrence or several flashes from the same individual during the transect course was counted as one occurrence. Fireflies were identified in field by their flashing pattern according to the authors experience on previous works [53] [54]. In case of doubt, the fireflies were collected with hand nets and identified by direct comparison with the Coleoptera collection at UFSCar. Environmental light intensities were measured in lux (wavelength peak at 530 nm; bandwidth = 470 - 650 nm) using a Skye SKL-310 photometer, by positioning the sensor at  $90^\circ$  to the ground before each transect was monitored. For direct light intensity, the sensor was positioned toward the light source.

## 2.4. Data Analysis

The software R version 3.0 was used for the statistical analysis and the generation of all graphs. A Kruskal-Wallis test was performed between six groups which were created by aggregating all transects and spotlight conditions. After that, a Wilcoxon test for each transect was carried out in regard of treatment spotlights *on* and *off*.

## 3. Results

### 3.1. Biodiversity

The following species were found among the 400 occurrences: (Lampyridae) *Photinus* sp1, *Aspisoma physonotum*, *Aspisoma lineatum*, *Amydetes fucata* and *Pyrogaster moestus*; (Elateridae) *Pyrearinus micatus* and *Pyrophorus divergens* (**Table 1**).

Lampyridae was the most represented family with 98% of the occurrences whereas Elateridae was represented with only 2%. The occurrence of *Photinus* sp1 was much higher in the investigated sites than all the other species, limiting our statistical analysis for this species (**Table 1** and **Figure 2**). **Figure 2** shows the mean monthly occurrence of Lampyridae species.

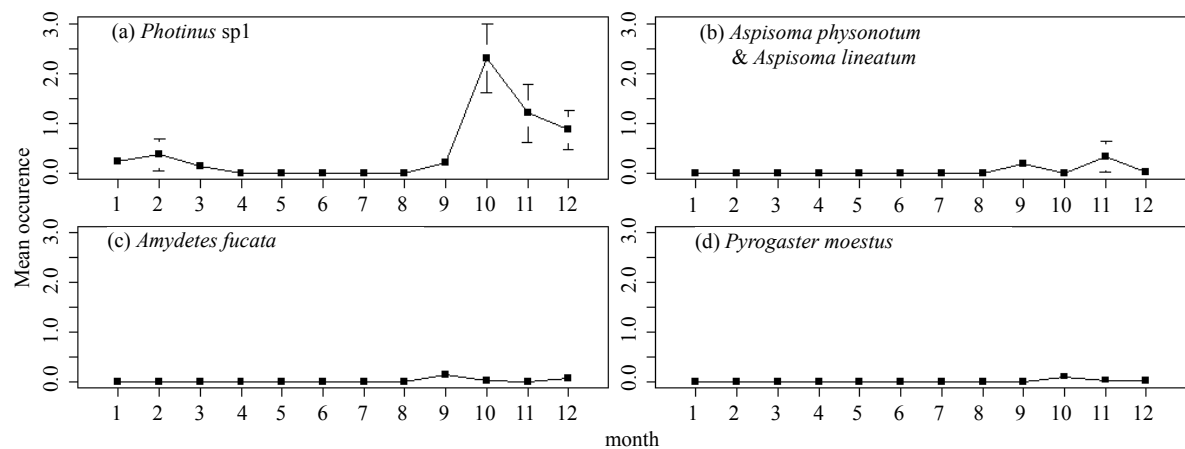
**Table 1.** Number and percentage of species for each transect and state of the spotlights.

	Light on (30%)*			Light off (70%)*			Total	%
	T0	T1	T2	T0	T1	T2		
Lampiridae								
<i>Photinus</i> sp1	6	30	58	43	91	100	328	82.00%
<i>Aspisoma physonotum</i> & <i>Aspisoma lineatum</i>	3	6	9	11	4	4	37	9.30%
<i>Amydetes fucata</i>	0	0	2	9	2	0	13	3.30%
<i>Pyrogaster moestus</i>	0	2	5	1	1	4	13	3.30%
Elateridae								
<i>Pyrearinus micatus</i> & <i>Pyrophorus divergens</i>	0	0	0	0	4	5	9	2.30%
Total	9	38	74	64	102	113	400	100%
n° of transects	125	117	121	113	122	111	709	

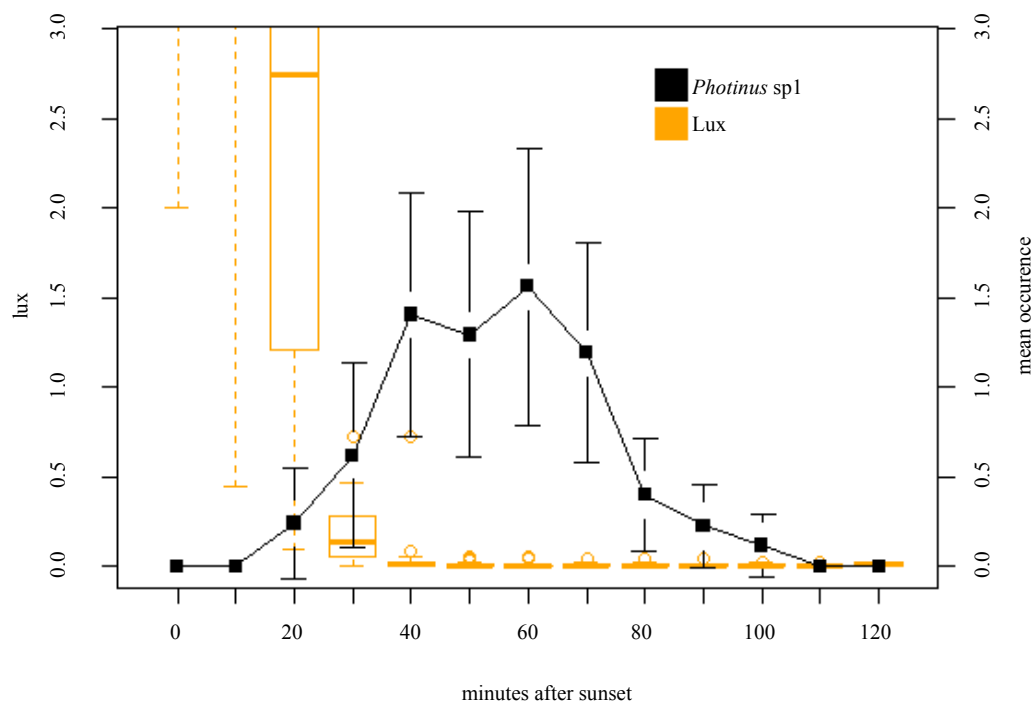
\*Absolute percentage of occurrences for each spotlight state.

Morphological and behavioral flash patterns observed in the field gave us confidence to identify the most occurring individuals above mentioned as the same morpho-species previously reported as *Photinus* sp1 [53] [54]. However, due to hindrances such as species descriptors older than one century, high local variation and lack of specialized taxonomists, *Photinus* sp1 could not be identified beyond genus. Nevertheless, priority was given to report a poorly explored but substantial threat to firefly populations, as we mean to underscore in this paper.

*Photinus* sp1 ( $\lambda$  max = 571 nm, yellow light) [53], was active from 20 - 100 minutes after sunset, with peak of activity at 50 minutes (see black mean plots in Figure 3). Flashing activity of the other fireflies was reported for *Aspisoma physonotum* and *Aspisoma lineatum* (20 - 100 min), *Amydetes fucata* (30 - 80 min), *Pyrogaster moestus* (30 - 70 min), *Pyrearinus micatus* and *Pyrophorus divergens* (30 - 40 min).



**Figure 2.** Monthly mean occurrences (confidence interval of 95%) for Lampyridae firefly species: (a) *Photinus* sp1, the most abundant species; (b) *Aspisoma physonotum* and *Aspisoma lineatum*, plotted together; (c) *Amydetes fucata*; (d) *Pyrogaster moestus*.



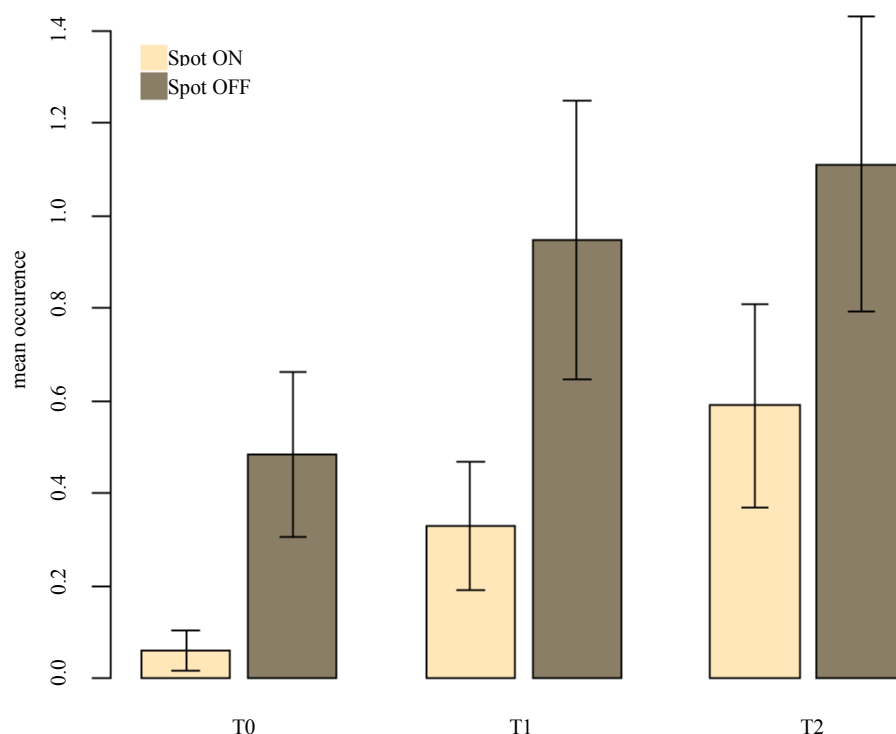
**Figure 3.** Relationship between the occurrence of *Photinus* sp1 (flashing activity, confidence interval of 95%) and environmental artificial luminosity (measured in lux) over time (in minutes after the sunset). Yellow boxes enclose 50% and lines 95% of the environmental artificial luminosity, and the median is indicated by the horizontal bar.

### 3.2. Night Lighting Intensities and Firefly Occurrence

The decay of natural environmental light stabilized around 40 - 50 minutes after the sunset (see yellow boxplots in [Figure 3](#)). At 40 minutes after sunset the direct light intensity of the Spotlights at T0 was  $4.45 \pm 0.001$  lux, T1  $1.5 \pm 0.001$  lux and T2  $0.05 \pm 0.001$  lux ( $n = 10$  measurements each). Comparatively, at full moon nights (without cloud cover and spotlights), the mean environmental light intensities was  $0.0438 \pm 0.044$  lux ( $n = 51$  transects). The highest observed intensity of artificial environmental light during flashing activity was 0.234 lux for *Photinus* sp1. For *Pyrogaster moestus*, *Aspisoma lineatum* and *Aspisoma physonotum* the highest observed intensities were between 0.001 - 0.05 lux in this site. There was a highly significant difference (Kuskal-Wallis  $P = 4.97 \times 10^{-7}$ ) between artificial groups of combined transects and spot states ([Figure 4](#)). The difference on the occurrence of *Photinus* sp1 on each transects (T0, T1 and T2) with different treatments, spots on and off, and the respective Wilcoxon test, is shown in [Figure 4](#).

## 4. Discussion

The time of flashing activity of fireflies is determined by natural environmental light levels [50]. Therefore a nighttime with excessive environmental light may affect the time of activity as well as the detection of bioluminescence signals emitted by potential sexual partners [50]. Furthermore, the activity of fireflies may also be influenced by the chromaticity of bioluminescence emission against the environmental photic background [50]. During the twilight in vegetated fields, the diffused ambient light spectrum is predominantly green [55], generating a green photic background which may interfere with the detection of bioluminescent signal of fireflies with similar bioluminescence spectrum. On the other hand, in full darkness, green bioluminescence will be reflected by foliage, turning the signal more easily detectable by the partner [55]. Conversely, individuals with yellow bioluminescence may have greater likelihood to detect intra-specific signals during twilight, due to the better contrast between yellow bioluminescence and the green photic background [49] [56].



**Figure 4.** Effect of direct illumination on *Photinus* sp1 occurrence. Mean occurrence of *Photinus* sp1 (confidence interval of 95%) at T0, T1 and T2 (difference of means = 87.4%, 65.2% and 46.9% respectively) with the light on ( $n = 363$  transects) and off ( $n = 346$  transects). A Wilcoxon test for mean occurrence on each transect among lights on and off had for T0, T1 and T2:  $P = 0.00015$ ,  $P = 0.04042$  and  $P = 0.01882$  respectively.



The flashing activity of *Photinus* sp1 starts from 20 minutes and lasts until 90 minutes after sunset (Figure 3) with peak at 50 minutes after the sunset, when it is already dark and the environmental light is stabilized (Figure 3). Although displaying yellow bioluminescence [53], which would put *Photinus* sp1 into the class of twilight active fireflies according to the North American category [50], *Photinus* sp1 is active mostly in the dark. This could be explained by the fact that in the Southeastern region of Brazil a clear relationship between firefly activity after sunset and bioluminescence color is not found, probably due to the shorter duration of twilight at lower latitudes when compared to higher latitudes of temperate zones [57]. We suspect the high relative abundance of *Photinus* sp 1 (Table 1) is related with a chronic photopollution exposure of the area, which possibly created a favorable environment for yellow glowing species.

The negative influence of artificial illumination on *Photinus* sp1 occurrence (Figure 4) can be explained by the strong and fast change in environmental night lighting scenario in the course of few years. Considering an evolutionary time scale of adaptation, the spotlights provided a direct illumination that was up to 100-fold stronger than the strongest natural light source (average lighting of full moon nights without cloud cover). Moreover the spotlights emit a polychromatic light, with bands peaking at different wavelengths that match firefly bioluminescence spectra, differentially affecting distinct species.

The main finding of this study is the influence of artificial nightlight (multi metal vapor spotlights direct illumination of 4.45 lux in T0  $\approx$  60 m) on *Photinus* sp1 occurrence based on its flashing activity. Despite the Wilcoxon test being significant only for T0 (Figure 4), the percentage of the mean difference for the areas farther from the spotlight were inversely proportional to the light source distance, suggesting that the average number of occurrences is considerably reduced in transects closer to the spotlights (from 47% up to 87% of occurrence suppression).

Although *Photinus* sp1 could not be identified yet, we can safely assure that it consists of a single species based on morphological characters, flash pattern and ecological aspects. Further studies are necessary to better understand the complete ecological impact of photopollution on firefly diversity and populations. First, the spectral characterization of artificially illuminated environments could reveal the impact of different kinds of polychromatic light sources on firefly photoecology (*i.e.* based on its relationship with bioluminescence spectra of persistent and locally extinct species). Second, sampling control areas historically distant from artificial light may help to better assess the effect of artificial light pollution.

## 5. Conclusion

Our findings illustrate the negative effect of artificial light on the activity of a *Photinus* species, thus providing a first quantitative evidence of artificial night lighting effects on firefly occurrence. We also propose fireflies as bioindicators and flagship species among nocturnal insects. Besides contributing to the promotion of the awareness regarding photopollution, this and complementary studies can hopefully provide subsidies to support stakeholders on creation of laws concerning artificial night lighting.

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