Lights that Extinguish Nature in Protected Forests: A Look at the Impact of Light Pollution

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Abstract

Light pollution has become established as a global environmental issue, driven by urbanisation and the growing use of artificial light at night (ALAN), which disrupts the natural rhythms of ecosystems. This phenomenon negatively affects biodiversity; particularly nocturnal species whose ecological interactions depend on darkness. This study assesses the impact of light pollution on protected forests in Guayaquil, Ecuador, specifically Cerro Blanco, Papagayo, Estero Salado, and Prosperina. Using VIIRS satellite imagery from 2014, 2019, and 2024, variations in nighttime radiance and their impact on local species such as Engystomops guayaco and Sylvilagus dauleensis were analysed. The results show an increase in light pollution near urban boundaries, particularly in Cerro Blanco, disrupting biological rhythms and threatening the survival of these nocturnal species. This study highlights the urgent need for public policies that promote sustainable lighting and the creation of "dark zones" to mitigate these effects and preserve biodiversity in these critical ecosystems.

1. Introduction

Light pollution has emerged as a growing environmental issue worldwide, resulting from the increased use of artificial light at night (ALAN), driven by urban development, industrialisation, and the widespread adoption of LED lighting technologies (Friulla and Varone, 2025). Over the past 25 years, global light intensity has increased by 49%, and it is expected that radiance in the visible spectrum will rise by 270%, with some regions potentially experiencing increases of up to 400%. This phenomenon leads to the progressive degradation of natural nighttime conditions, a process known as nocturnal erosion (de Miguel et al., 2021).

Various studies have documented that artificial light at night significantly disrupts essential ecological dynamics. The effects of this lighting are not limited to the illuminated areas but spread to adjacent zones, affecting vital ecological services such as predation and pollination (Giavi et al., 2020). Disruption of the light-dark cycle alters species interactions and can reconfigure trophic networks (Sanders and Gaston, 2018). In response, several authors have proposed integrating dark infrastructure into land-use planning to mitigate the effects of light pollution and protect biodiversity, warning that the loss of natural darkness is an increasing pressure on nocturnal wildlife (Sordello et al., 2022).

The effects of light pollution have impacted ecological systems in various regions of the world (Bará and Falchi, 2023). Light pollution, along with other factors such as anthropogenic activity and pollution, can contribute to the degradation of ecosystems (Fröhlich et al., 2025). In Latin America, countries like Chile and Colombia have documented significant losses in the visibility of the night sky, leading to increased urban luminosity and the gradual degradation of natural skies, highlighting the need for sustainable light management policies in the region (Angeloni et al., 2023; Uchima-Tamayo et al., 2025).

Studies on nighttime lighting in Ecuador have shown that cities with greater urban development have the highest levels of radiance detected by satellite, directly contributing to night glow and the loss of dark skies (Watson et al., 2023). Guayaquil is surrounded by remnants of protected forests, such as Cerro Blanco and Papagayo, and within the city are the forests of Prosperina and Estero Salado. These ecosystems are essential refuges for various species, including endemic birds, mammals, reptiles, amphibians, and insects. A notable example is Engystomops guayaco, a nocturnal, endemic amphibian from Ecuador, which has been severely threatened by habitat loss. It is currently listed in the Red List of Amphibians of Ecuador due to the loss of its natural environment (Ortega-Andrade et al., 2021).

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Various studies have used different methodologies to quantify light pollution globally. A large-scale study analysed nighttime light trends in 216 places certified as International Dark Sky Places (IDSPs) using VIIRS Nighttime Light Composite satellite data, applying statistical analyses, such as the Mann–Kendall test and regressions, to detect variations in artificial light levels between 2012 and 2020 (Aksaker et al., 2026). Another approach used the GLOBE at Night citizen photometry methodology, which collects millions of observations on star visibility worldwide to validate light pollution models (Kyba et al., 2013). Additionally, all-sky photometry techniques and measurements with Sky Quality Meters (SQM) have been used in environmental studies to map the spatial and temporal variation of sky brightness and analyse the impact of various sources of artificial light in urban and rural areas (Deverchère et al., 2022).

In Ecuador, studies on light pollution are limited, despite its negative effects on local biodiversity. It is essential to strengthen research to better understand the issue and promote public policies to mitigate this environmental degradation. The main objective of this study is to assess the impact of light pollution on the flora and fauna of the protected forests of Guayaquil, using VIIRS nighttime satellite images from 2014, 2019, and 2024.

2. Study area

The study area focuses on the hills of Guayaquil (Figure 1), specifically the tropical dry forests of Cerro Blanco, Papagayo, Estero Salado, and Prosperina, located in the Guayas province, Ecuador (Horstman, 2017). These ecological zones are vital for the conservation of local biodiversity, as they host both endemic and migratory species and play a significant role in regulating the region's environment (Mestanza-Ramón et al., 2023). Over the past decade, Guayaquil has experienced heterogeneous and disordered urban growth (Castro-Rodas et al., 2026; Freire-Granda et al., 2026; Martínez-Angulo et al., 2026), which has led to increasing light pollution that directly affects the dry forests, altering the natural patterns of local flora and fauna (Aguilera and González, 2023). Figure 1 visualises the proximity between urban growth and natural areas, highlighting the urgent need to assess and mitigate the impact of light pollution on biodiversity in these protected areas (Portalanza et al., 2024).

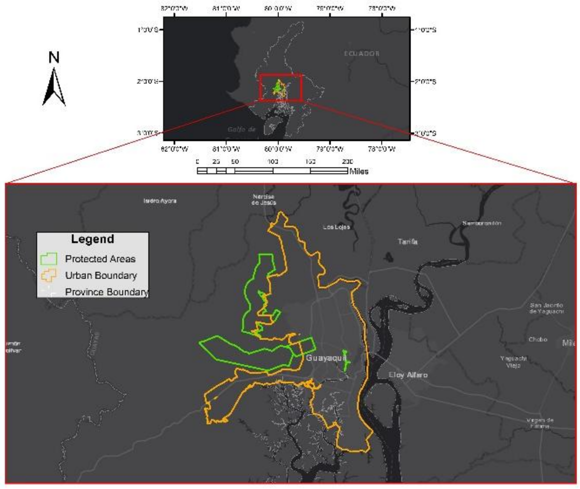

Figure 1. Study area: Location of the protected areas and the urban boundaries of Guayaquil, Ecuador.

3. Methodology

The methodological flowchart (Figure 2) describes the workflow implemented to assess the effects of light pollution on the flora and fauna in the protected areas of the Guayaquil canton. The process began with the acquisition of nighttime satellite images and data on the location of flora and fauna species. These data were processed in Google Earth Engine (GEE) to generate average annual radiance images, which were then classified into light pollution categories (Velastegui-Montoya et al., 2023). Subsequently, spatial analyses were conducted in ArcGIS Pro to intersect these results with species locations, enabling the identification of affected areas and species influenced by light radiation. This methodological flow provides a foundation for understanding the environmental impact in the study areas.

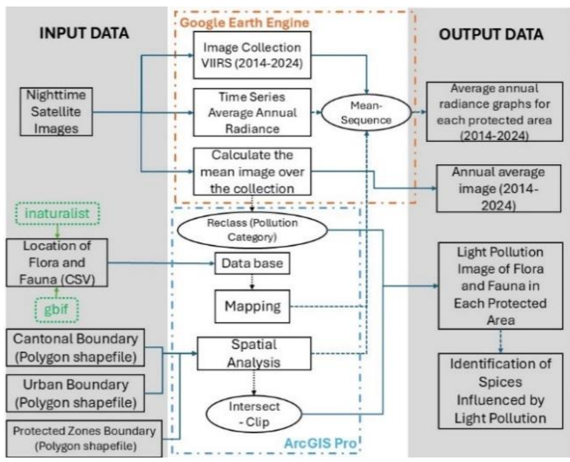

Figure 2. Methodological Flow for the Evaluation of Light Pollution in Protected Areas of Guayaquil

Data Acquisition

In this phase, relevant information was collected from various platforms and geospatial sources. First, through the GEE platform, nighttime satellite images from the NOAA/VIIRS/DNB/MONTHLY_V1/VCMSLCFG collection were obtained, specifically the average radiance band (avg_rad), to assess temporal variations in light radiation. Additionally, spatial data on the canton and urban boundaries of Guayaquil were acquired from the Military Geographic Institute's platforms and the Municipality of Guayaquil's geoportal in shapefile format, providing territorial information for the study area. Furthermore, CSV-format data on the locations of flora and fauna in the protected areas of the Guayaquil canton were downloaded from the iNaturalist and GBIF platforms. Finally, data on the protected areas (Cerro Blanco, Papagayo, Estero Salado, and Prosperina) were collected from the Ministry of Environment's geoportal in shapefile format and used to delimit the areas of ecological interest for the analysis.

Image Processing

Satellite image processing was performed on the GEE platform using VIIRS imagery from 2014 to 2024. These were filtered by the area of interest (the Guayaquil canton), and the average radiance across all months during this period was calculated. The resulting image, representing average nighttime radiance (nanoWatts/sr/cm²), was cropped to the geometry of the area of interest (AOI) and visualised using a colour palette that facilitated interpretation of radiance variations over time. This step provided an overview of light radiation distribution in the study region, creating a map that illustrated the areas with the highest and lowest levels of light pollution.

Time Series Analysis

To understand the evolution of light radiation over time, a time-series analysis was conducted using VIIRS satellite imagery for the period 2014-2024. This analysis focused on the annual evolution of radiance for the selected forests: Cerro Blanco, Papagayo, Estero Salado, and Prosperina. The average radiance values per year were calculated using the reduceRegion() operator, with a spatial resolution adjusted to 463.83 meters. The results were organised into a feature collection (FeatureCollection), allowing for the generation of an interactive line graph to observe the temporal trends of radiation in each protected area. This analysis facilitated the identification of patterns and fluctuations in light pollution throughout the study period.

Generation of Raster Images

In the next phase, the average nighttime radiance images for the period 2014-2024, cropped to the boundaries of the protected areas (Cerro Blanco, Papagayo, Estero Salado, and Prosperina), were processed. This step was carried out in ArcGIS Pro software, where individual raster images were generated for each area. These images were then classified into three radiance categories: low (0.35 - 0.6 nanoWatts/sr/cm²), medium (0.6 - 6 nanoWatts/sr/cm²), and high (6 - 30 nanoWatts/sr/cm²) (Elvidge et al., 2021; Xu et al., 2019). Image classification enabled the identification of light pollution intensity in each area and the establishment of criteria to assess its impact on local fauna and flora, particularly in protected areas.

Analysis of Flora and Fauna in Protected Areas

Once the radiance rasters were classified, these data were intersected with the location of flora and fauna within the protected areas. The species location information, previously downloaded in CSV format, was converted to shapefile format to enable integration with ArcGIS Pro. This analysis enabled the identification of which flora and fauna species in the protected areas were exposed to different levels of light pollution, based on the radiance categorisation obtained in the previous phase. By intersecting the species location data with the low, medium, and high radiance zones, the potential impact of light pollution on the region's biodiversity was determined, providing important data for the conservation of these ecosystems.

Visualisation and Results

Finally, the results from processing and analysis were visualised and presented in interactive maps and graphs, facilitating the interpretation of variations in nighttime radiance in the protected areas. The data were presented to highlight trends in light radiation and its relationship to the location of flora and fauna. These results were integrated into this article, providing information for decision-making in conservation policies and environmental management, and contributing to understanding the impact of light pollution on Guayaquil's biodiversity.

4. Results

The analysis of light radiation in protected areas near the city of Guayaquil, using VIIRS satellite images from 2014, 2019, and 2024, has shown a clear increase in light pollution levels in areas close to urbanisation. In protected areas such as Cerro Blanco Forest, Estero Salado, Papagayo, and La Prosperina, a growing trend of increased light radiation was observed, especially near urban boundaries, suggesting that the expansion of urban infrastructure is impacting these natural ecosystems.

Figure 3 shows the evolution of light radiation over the years; the graphs describe a generalised increase in pollution levels. In the Papagayo Forest, for example, radiation peaked in 2018, with an average close to 5.5 nW/sr·cm², before gradually decreasing (Figure 3a). This pattern of increase followed by decrease was also reflected in La Prosperina, where radiation exceeded 25 nW/sr·cm² in 2016, with fluctuations in the following years (Figure 3b). In Estero Salado, although radiation was more stable, a significant increase was observed in 2017 and 2018, followed by a drop in recent years (Figure 3c). The Cerro Blanco Forest showed a more moderate trend, with small radiation peaks in 2017 and 2018, but without the extreme variations observed in other forests (Figure 3d).

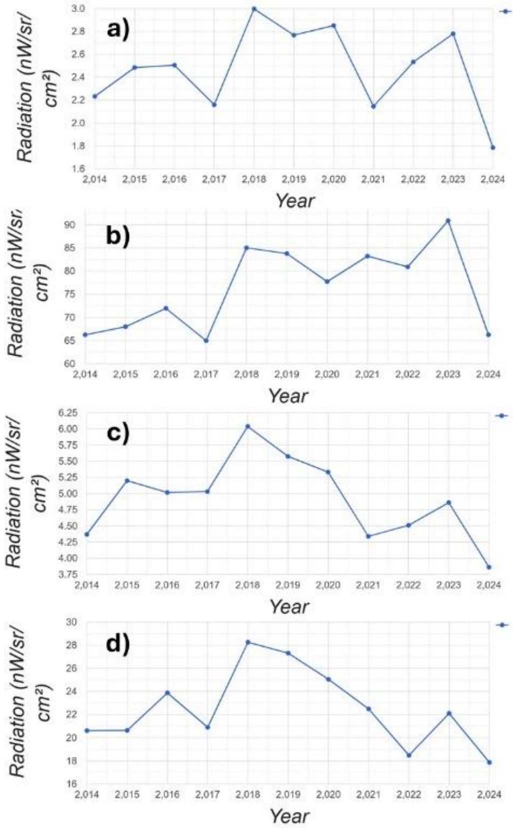

Figure 3. Annual evolution of average light radiation in the protected forests of Guayaquil: a) Cerro Blanco, b) Estero Salado, c) Papagayo Forest, d) La Prosperina Forest.

Table 1 shows the species affected by light radiation in the protected areas of Guayaquil. In the Cerro Blanco Forest, 111 species were recorded as exposed, mainly insects, mammals, and birds, with exposure to medium- and high-level pollution. The Estero Salado Forest had 17 species affected, mainly amphibians and mammals, with high radiation. In the Papagayo Forest, 7 species were identified as affected, mainly amphibians and mammals, with medium pollution. The La Prosperina Forest had 206 species, primarily insects and birds, exposed to high radiation. Areas close to urbanisation, such as La Prosperina, show a higher concentration of species in areas of high light pollution, which jeopardises the conservation of these nocturnal ecosystems.

The species distribution maps (Figure 4) show the spatial concentration of species exposed to elevated levels of light pollution, especially at the edges of urban boundaries and expansion corridors, suggesting a "spill light" effect, or light spill, into forest environments (Aguilera and González, 2023b; Mariton et al., 2022)Nocturnal species such as *Engystomops guayaco and Sylvilagus dauleensis*, both sensitive taxa with biology strongly linked to periods of darkness, are recorded in areas with high levels of ALAN, which aligns with evidence that artificial light disrupts circadian rhythms and nocturnal activity in animals, affecting their behaviour, reproduction, and survival (Hölker et al., 2010).

Location	Class	Number of Classes/Affected Level	Total Number of Affected Species
Cerro Blanco Protected Forest	Actinopterygii	2	111
	Amphibia	7	
	Arachnida	14	
	Aves	8	
	Fungi	11	
	Insecta	13	
	Liliopsida	7	
	Magnoliopsida	25	
	Mammalia	20	
	Mollusca	1	
	Reptilia	3	
Estero Salado Protected Forest	Amphibia	1	17
	Arachnida	1	
	Aves	3	
	Fungi	3	
	Insecta	1	
	Mammalia	2	
	Mollusca	2	
	Plantae	4	
Papagayo Dry Forest	Amphibia	1	7
	Amphibia	2	
	Fungi	1	
	Insecta	1	
	Mammalia	1	
	Reptilia	1	
La Prosperina Protected Forest	Amphibia	3	206
	Amphibia	11	
	Arachnida	6	
	Arachnida	14	
	Aves	23	
	Fungi	4	
	Fungi	22	
	Insecta	10	
	Insecta	56	
	Mammalia	4	
	Mammalia	31	
	Mollusca	9	
	Reptilia	4	
	Reptilia	9	
Pollution level	**LOW**	**MEDIUM**	**HIGH**

Table 1. Light pollution levels and number of affected species in the protected forests of Guayaquil: Cerro Blanco, Estero Salado, Papagayo, and La Prosperina.

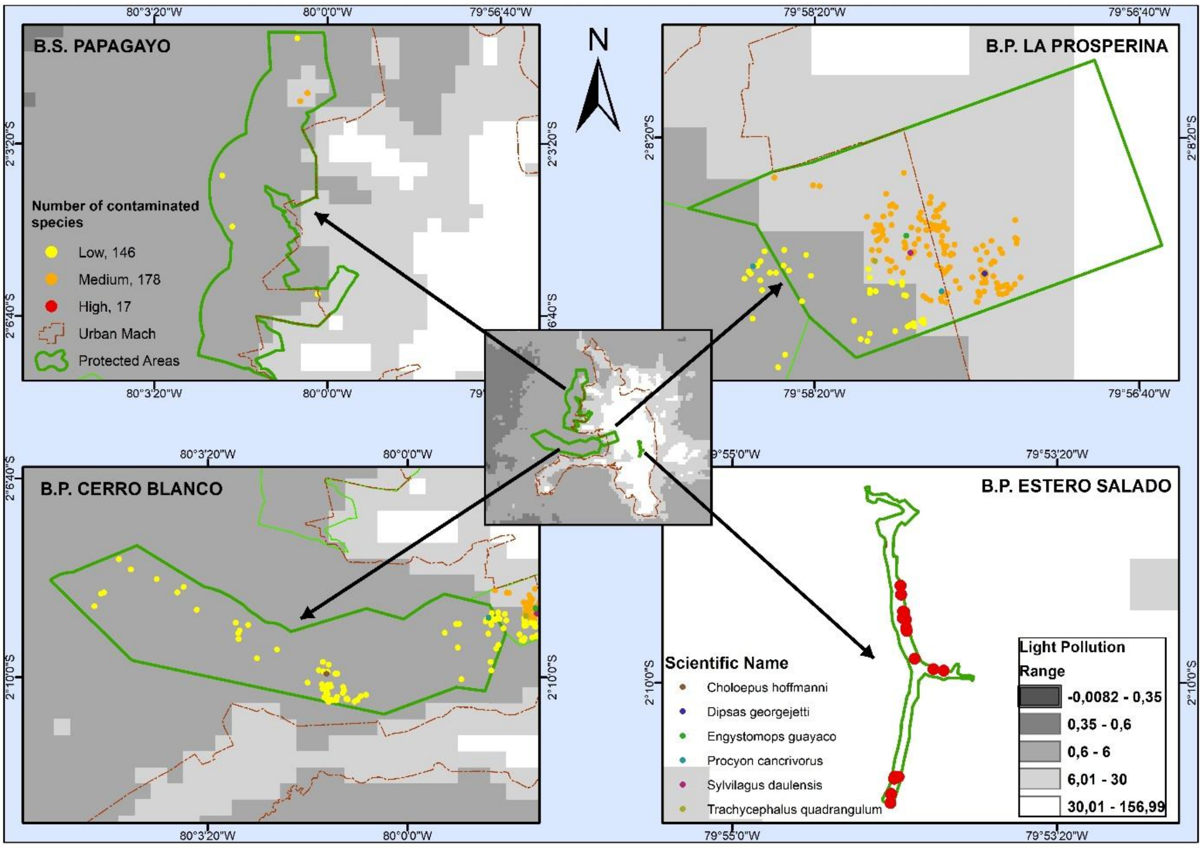

Figure 4. Geographic distribution of species affected by light pollution levels in the protected forests of Guayaquil: Papagayo, Cerro Blanco, Estero Salado, and La Prosperina.

5. Discussion

The results reinforce the evidence that light pollution is an increasing environmental stressor, especially in protected areas with sensitive ecosystems (Dominoni et al., 2013). Urban expansion and the intensive use of artificial light, such as in Guayaquil, directly affect local wildlife, disrupting their circadian cycles, migration, and reproduction, putting the survival of endemic and migratory species at risk (Shier et al., 2020).

The highest concentration of species affected by light pollution is in La Prosperina, with 206 species exposed. This area near Guayaquil has high exposure to pollution, especially in insects and birds, which are affected by elevated radiation levels. This finding aligns with studies showing that urban areas disrupt the biological cycles of species through artificial light at night (Guetté et al., 2018).

The impact of light pollution extends beyond urban areas. In the Cerro Blanco Forest, despite its distance from the city, 111 species were recorded as affected, reflecting the expansion of artificial light into natural areas through urban corridors. Species exposed to medium and high radiation levels include mammals, insects, and birds, which rely on dark cycles for feeding and reproduction (Bará and Falchi, 2023; Mariton et al., 2022).

The impact on species such as *Engystomops guayaco and Sylvilagus dauleensis*, which rely on darkness for their essential biological cycles, highlights the disruption of their circadian and reproductive rhythms. Their presence in areas with high light radiation reflects how artificial light is altering their natural environment, affecting their crucial nocturnal activities that depend on darkness.

Although Estero Salado and Papagayo had fewer species affected (17 and 7, respectively), the presence of *Amphibia and Mammalia* species in areas with high light radiation in Estero Salado shows that even in forests far from urban areas, the effects of light pollution are harmful. This confirms that artificial light spreads beyond urban boundaries, affecting even remote and protected areas (Jägerbrand and Bouroussis, 2021).

Urbanisation and the expansion of illuminated infrastructure have intensified light pollution, especially around Guayaquil, where protected areas are being invaded by artificial radiation. The spread of light beyond urban areas is negatively affecting local biodiversity, as observed in nearby areas such as La Prosperina and Estero Salado. This confirms that light pollution impacts even areas with conservation status (Guetté et al., 2018).

Although the studied areas have conservation status, urban expansion and increased light pollution highlight the need for effective public policies that promote sustainable lighting technologies (Barta et al., 2014; Méndez et al., 2024). Measures such as efficient lighting, reducing light intensity in sensitive areas, and creating "dark zones" are essential to mitigate the impact on these ecosystems (Jägerbrand and Bouroussis, 2021). Additionally, policies should integrate an approach that protects species and their natural environments and restores the darkness necessary for their survival (Zheng et al., 2021).

This study highlights the growing impact of light pollution on the protected areas near Guayaquil, severely affecting species that depend on darkness for their biological cycle. This jeopardises their ecology and emphasises the urgency of taking measures to reduce light pollution and protect nocturnal biodiversity. It is essential to implement public policies that manage lighting sustainably, respect natural rhythms, and promote conservation (Gaston and Sánchez De Miguel, 2022).

6. Conclusion

This study has highlighted the growing impact of light pollution on the protected areas near Guayaquil, Ecuador, particularly on nocturnal species such as *Engystomops guayaco and Sylvilagus dauleensis*. Analysis of VIIRS satellite images showed a significant increase in light radiation in forests such as Cerro Blanco and La Prosperina, which is affecting the biological rhythms of these species. Despite the conservation status of these areas, urban expansion remains a threat. It is urgent to implement public policies that reduce light pollution, use sustainable lighting technologies, and create "dark zones" to restore natural darkness cycles essential for biodiversity.

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