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Papers

Cartography in Nocturnal Landscapes: Exploring Biodiversity, Lighting and Open Spaces

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Abstract
The nocturnal landscapes host unique fauna and flora dynamics, sheltering camouflaged natural processes that have been insufficiently acknowledged in city planning and design. Recent urban studies have pointed out that urban lighting can fragment the nocturnal habitat, demanding new guidelines and strategies in urban lighting design. This paper aims to explore design and planning potentialities that support nocturnal landscape biodiversity, looking at interrelationships between ecological and sociocultural dimensions of the urban landscape. Drawing on a case study in the city of Rio de Janeiro—in an area between the mountains and the sea—this paper uses cartography as an interdisciplinary approach to analyze the nocturnal urban biodiversity, brightness and explores possibilities for nocturnal urban planning. Cartography was a catalyst for implementing methods such as fieldwork, mapping, interviews and bibliographic research, gathering data from different fields, mainly between urbanism and ecology. The article results reveal the existing nocturnal biodiversity in the study area and its environmental sensitivity, exploring mediations between urban lighting and the landscape's ecological and sociocultural dimensions. From the findings, the paper suggests preliminary guidelines for planning nighttime environments more sustainably through green–blue landscape networks. This paper seeks to integrate the nocturnal landscape into the urban agenda, expanding the debate on urban biodiversity and open spaces.

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INTRODUCTION

The nocturnal landscapes are home to unique fauna and flora dynamics, encompassing distinctive natural processes. At night, flowers bloom, open and release perfumes; nocturnal animals begin their journeys camouflaged in the landscape; and some species interactions start in unique ways. Recent studies have connected urban planning with lighting and ecology, looking at how city lights affect biodiversity (Challéat, 2018). The idea of a *trame noire* (dark ecological network) in public policy—which is associate to blue–green ecological networks—is designed to restore and protect the nocturnal habitat.

Conventional design guidelines are no longer enough to encompass the complexity of nocturnal territory. It is necessary to cross scales and develop interdisciplinary methods for planning urban lighting approaches (Sordello *et al.*, 2021). Nevertheless, in order to keep biodiversity, nocturnal planning requires central areas of darkness, which does not happen in the dense urban tissue of Rio de Janeiro. Cultural views and values make it difficult to see lighting as harmful to the environment. Meanwhile, habitat loss, climate change, declining biodiversity and discussions of nature as a subject of rights in Latin America (Gudynas, 2014) have inspired strategies for promoting biodiversity in the city.

Urban planners and conservation biologists should recognize the importance of urban biodiversity in environmental management efforts, as management decisions require comprehensive information about fauna and flora that habit the city (Jokimäki *et al.*, 2011). In this sense, even beyond conservation areas, urban green spaces play a crucial role in maintaining the natural processes and flows involved in biodiversity (Benedict; Mcmahon, 2006). These open spaces provide essential ecosystem services, enhance environmental quality, support drainage, facilitate organic matter processing and enhance residents' health and well-being (Hough, 1995; Farinha-Marques *et al.*, 2014).

This paper is inspired by the idea of landscape mediation, which involves studying the relationship between cultural and ecological processes in the landscape (Corner, 2006). Our core premise is that landscape is a place of coexistence, where human beings are not the focus but rather one inhabitant alongside plants and animals (Besse, 2018). The central question of this paper is as follows: How to rethink the city lights? In this sense, this article explores design and planning potentialities that support nocturnal landscape biodiversity, looking at interrelationships between ecological and sociocultural dimensions of urban landscape.

Drawing on a case study in the city of Rio de Janeiro—in an area between the mountains and the sea—this paper adopts an interdisciplinary approach through cartographic methods. Cartography was a catalyst for implementing methods such as fieldwork, mapping, interviews and bibliographic research to collect data from different fields (e.g., ecology, urbanism and landscape architecture). Some aspects of the cartographic method were previously discussed in relation to the historic dimensions of this case study (Ferreira, 2026). In this paper, the discussions of cartography focus on Rio de Janeiro's urban biodiversity.

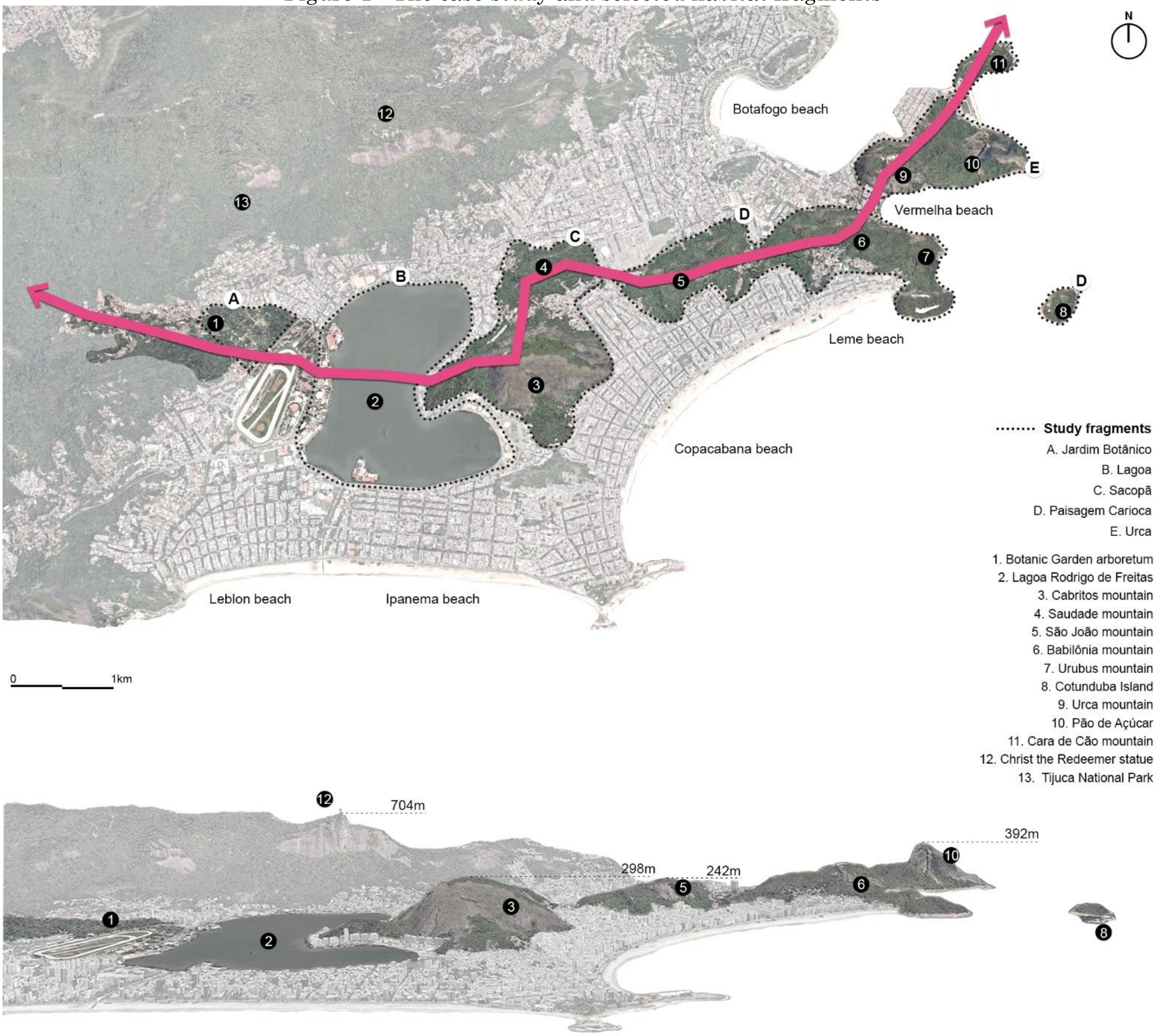
Rio de Janeiro is composed of environmental richness, surrounded by mountains, rainforests, variability of altitudes, coastal areas and conservation units are spread across densely built urban tissue. Additionally, boundaries between city and forests are difficult to define. Both formal and informal settlements can be found bordering or within forested areas. These heterogeneities make this city a relevant place to discuss environmental issues and urban lighting. Many studies have brought significant contributions, examining the social dynamics of Rio de Janeiro at night (Góis, 2014; Carvalho, 2013). From a different perspective, this paper aims to bring a contribution to ecological dimension of nocturnal landscape.

BETWEEN THE MOUNTAINS AND THE SEA: A CASE STUDY IN RIO DE JANEIRO

Rio de Janeiro covers an area of approximately 1,000 km² and has over 6,700,000 inhabitants. The city features remnants of the Atlantic Forest biome and its associated ecosystems. This biome receives more rain on the slopes facing the ocean, leading to a highly diverse environment in which plants and animals have evolved within overlapping and interdependent living networks (Galindo-Leal; Câmara, 2005). The dense urbanization of Rio de Janeiro has transformed forest fragments into isolated areas within the city (Figure 1).

The case study was situated in these fragments, along the edge of the Tijuca Massif, in an area encompassing several high-income neighborhoods in the South Zone of Rio de Janeiro and remaining *favelas*. We selected five fragments comprising a potential ecological corridor (Figure 1) to detail the urban biodiversity therein: *Jardim Botânico do Rio de Janeiro* (Botanical Garden of Rio de Janeiro - JBRJ) (A), *Lagoa Rodrigo de Freitas* and its margins (B), *Sacopã* (C), *Paisagem Carioca* (D) and *Urca* (E).

Figure 1 - The case study and selected habitat fragments



Source: The authors (2025).

CARTOGRAPHIC AND METHODOLOGICAL STRATEGIES

Landscapes and representations have an intrinsic relationship. Corner (1992) made connections between design, landscapes and representation, noting that one of the central characteristics of the landscape is the way it is represented. Corner (1999a) claimed that mapping can provide opportunities for urban planning and design that consider social and spatial processes—unlike universal planning approaches. According to Cosgrove (1999), not only is all mapping cognitive, they are historically and culturally specific, but all mapping involves sets of choices, omissions, uncertainties and intentions.

In doing so, mappings have agency, they are not neutral, being formative and creative act of design process. They enable the exploration of multi-layered landscapes, "uncovering realities previously unseen or unimagined" (Corner, 1999a, p. 213). This research aims to represent and juxtapose investigation topics and to identify landscape processes that have generally gone unmapped. Multiple data sources are used, including data, texts, images, scales, diagrams and hybrid compositions (Corner, 1999b).

The cartographic method employed in this case study integrated mixed methods across five complementary stages. First, we looked at the city from above, attempting to understand the ecological network and dense urban matrix in the study area. Initiated in March 2022, these exploratory walks served as fieldwork in which we updated the recorded distribution of vegetal species of the *Lagoa Rodrigo de Freitas*, from the edge of the lagoon to the edges of main avenues.

The second stage involved an extensive literature review for selected taxonomic groups to obtain data on the presence of species in studies, rapid ecological assessments or management plans developed for each study fragment, considering only data collected through fieldwork. The biodiversity dataset collected is a compiled and partial inventory to explore environmental sensitivity; this is not a comprehensive nocturnal survey. For more information about this inventory, see Ferreira (2024).

The *Instituto Chico Mendes de Conservação da Biodiversidade* (Chico Mendes Institute for Biodiversity Conservation - ICMBio) highlights four main groups for those monitoring biodiversity: birds, woody plants, frugivorous butterflies and medium and large mammals (Pereira *et al.*, 2013). Regarding nocturnal biodiversity, Sordello *et al.* (2018) emphasize species that could be more affected by artificial light, such as bats, mammals and nocturnal insects. Therefore, this paper classified the data into three groups: birds, trees (shrubs, trees and palm trees) and mammals (flying and nonflying; aquatic mammals were excluded).

The third stage involved mapping brightness, biodiversity and blue–green open spaces. When analyzing urban biodiversity in Porto city, Farinha-Marques *et al.* (2014; 2017) mapped and classified green spaces and natural spaces, such as beaches, rivers, forests and rocky outcrops. Green spaces were defined as outdoor, non-built areas hosting vegetation with ecological and landscape value. Their classification considers ecological and sociocultural factors, such as design, function, maintenance, vegetation cover, soil permeability, public or private status and location in natural subsoil or overbuilt areas.

Drawing on satellite images from Google Maps, this article mapped seven types of green spaces: planted median, tree-lined streets, parks (with restricted or unrestricted access), squares and gardens, green spaces related to military, educational and recreational features, green spaces associated with culture, and green spaces associated with non-forest arboreal vegetation.

Artificial light at night (so-called ALAN) is a multidisciplinary topic of discussion interpreted using different conventions and measuring instruments. However, the ecological relevance and efficacy of such methods remain uncertain (Hölker *et al.*, 2021). Several sources of data facilitate the technical discussion of urban lighting, including power, color temperature and luminous flux. There are also *in situ* measurements of light. For example, the brightness of the night sky can be measured using a sky quality meter.

There are no official data on light pollution or technical georeferenced data on urban lighting in Rio de Janeiro, so we used the Radiance Light Trends website and satellite data from October 2022 to estimate brightness (Stare; Kyba, 2019). Using a selected pixel (750 x 750 m) to get closer to the fragment area, we collected VIIRS DNB data with zero-point correction. The data do not provide precise information on light pollution but instead capture gradients of reflected light, suggesting possible habitat fragmentation at night. The satellite's spectral range is less sensitive to the spectrum emitted by white LED lights, showing limitations of this method.

All mapping was performed using QGIS 3.30.2 (2023), which served as an overlay tool; subsequently, the maps were completed in Illustrator software. For blue-green networks, shapefiles were created, and georeferenced data on vegetation cover and land use were collected (IPP, 2021). For brightness, we created shapefiles from CSV files with the Radiance Light Trends data (Stare; Kyba, 2019). For fauna and flora sensitivity, we classified them according to table 1, creating diagrams in Excel. The corridors indicated were estimated from minor distances measured visually.

The fourth stage involved in-depth interviews. Within the broader research project, the interviews centered on the values and meanings attributed to the nocturnal landscape among experts and residents (Ferreira, 2024). In this paper, we draw on 14 interviews with experts, such as architects, lighting designers, biologists, astronomers, and urban planners. The interviews were conducted virtually (with a few exceptions) between May 2022 and May 2023, covering different thematic analyses according to the interviewee's profile, such as urban lighting, lighting pollution and ecological dynamics and biodiversity of the study area. Although we follow a checklist of topics for the interview, they have the format of a conversation where the respondent is set at ease to speak freely.

Consent forms were obtained and submitted to the *Comitê de Ética em Pesquisa do Centro de Filosofia e Ciências Humanas/ Universidade Federal do Rio de Janeiro* (Research Ethics Committee of the Center of Philosophy and Human Sciences/ Federal University of Rio de Janeiro, process number 5.379.63). This research was also authorized by the *Sistema de Autorização e Informação em Biodiversidade* (Authorization and Information on Biodiversity System - SISBIO, process number 84461-1).

Finally, a new theme emerged during the research: the sensitivity of animals and plants in urban and anthropized spaces, which could be an indicative to sensitivity to lighting. Researchers have discussed the persistence of species in urban habitats (Jokimäki *et al.*, 2011), which has been attributed to opportunism and plasticity—a key ecological behavior—by the biologists interviewed. According to them, in urban areas, species are typically generalists and not endemic or exotic. Other species are specialists, such as endemic and native species, which may be more sensitive to lighting than exotic organisms.

In addition to the potential threats, this study postulates—following the suggestions of some biologists interviewed—that animals which inhabit open areas concomitantly with edge or forest areas have greater plasticity, as they are less dependent on forests. According to the interviews with some biologists, animals with greater environmental plasticity may be more tolerant of habitat disturbances (e.g., exposure to atmospheric and light pollution). In contrast, animals from forest habitats are more sensitive to environmental changes. Based on this topic and given the gaps in studies on the impacts of lighting on Brazilian fauna and flora, this paper examines the environmental sensitivity of the flora and fauna in the selected fragments (Table 1 and

Figure 2), focusing on species that are active at night as well as those that are active during the day but also demonstrate nighttime or twilight activity.

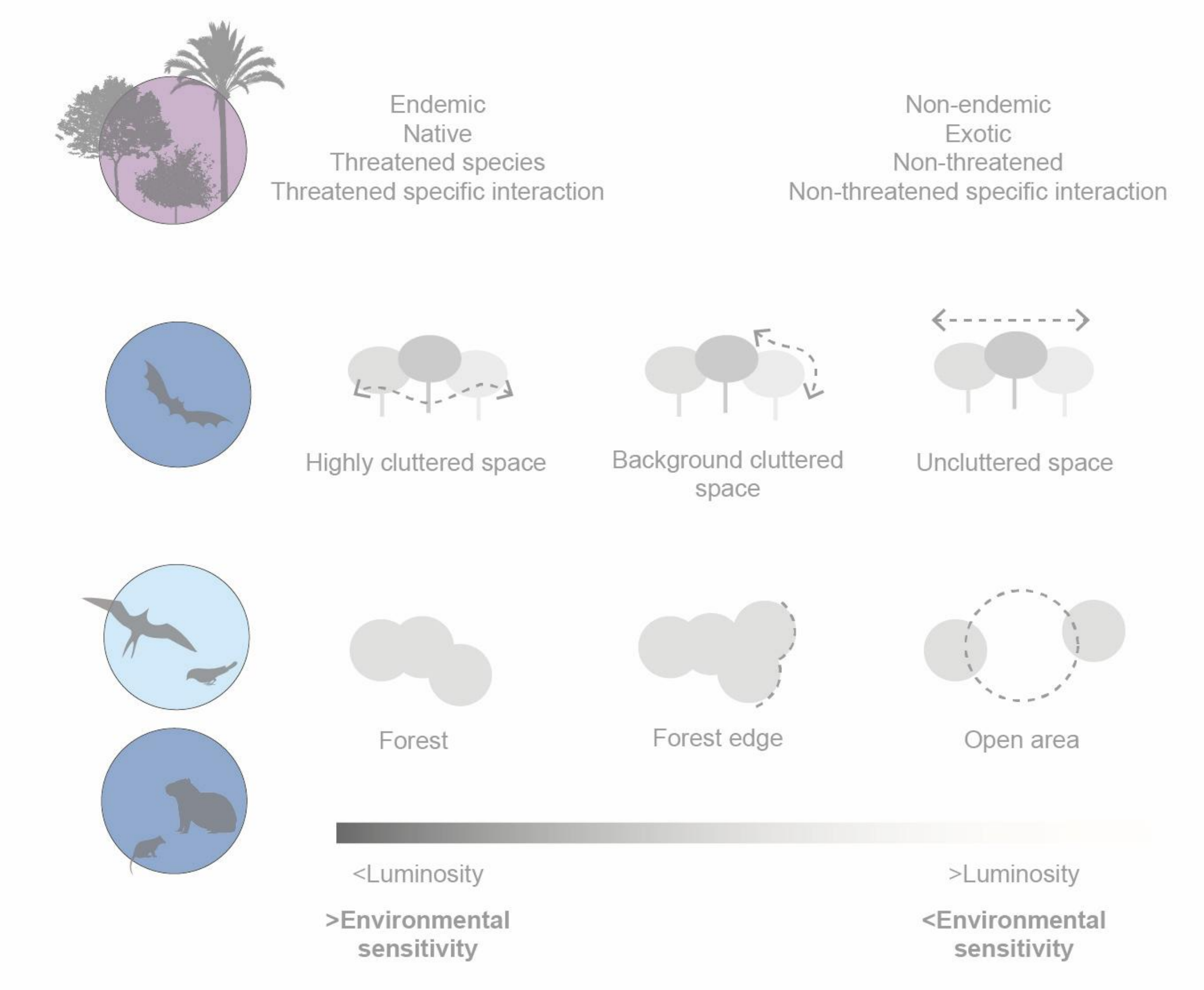
Table 1 – Criteria for environmental sensitivity

Groups	Criteria for analysis	References
Trees	Endemism	Flora e funga do Brasil (2023)
	Origin (native or exotic)	Flora e funga do Brasil (2023)
	Threatened species*	CNC Flora (2012), SMAC (2022a)
	Specific interaction (pollination, feeding, roosting	Bibliography research (see Appendix 5 in Ferreira, 2024)
	Endemism	Pacheco et al. (2021)
	Habitat (open area, forest edge, or forest)	Sick (2001)
Birds	Threatened species*	SMAC (2022b), Bergallo *et al.* (2000), IUCN (2023)
	Status (resident or seasonal visitor)	Pacheco *et al.* (2021)
	Plasticity	Stotz *et al.* (1996), Interviews with experts
	Endemism (endemic or not)	Paglia *et al.* (2012)
	Habitat (open area, forest edge, or forest)	Reis *et al.* (2011)
Mammals (non-flying)	Threatened species*	SMAC (2022b), Bergallo *et al.* (2000), IUCN (2023)
	Plasticity	Cassimiro *et al.* (2023), Reis *et al.* (2011), Rios *et al.* (2022)
	Endemism	Paglia *et al.* (2012), Quintela *et al.* (2020)
Mammals (flying)	Highly cluttered space, background cluttered space, uncluttered space	Kalko *et al.* (1996)
	Threatened species*	SMAC (2022b), Bergallo *et al.* (2000), IUCN (2023)
	Plasticity	Reis *et al.* (2007), Pires; Cademartori (2018)

*LC (Least concern), NT (Near threatened), VU (Vulnerable), EN (Endangered).

Source: The authors (2025), see appendix 11 in Ferreira (2024).

Figure 2 – Estimating environmental sensitivity



Source: The authors (2025).

ECOLOGICAL NETWORKS, BRIGHTNESS AND NOCTURNAL BIODIVERSITY

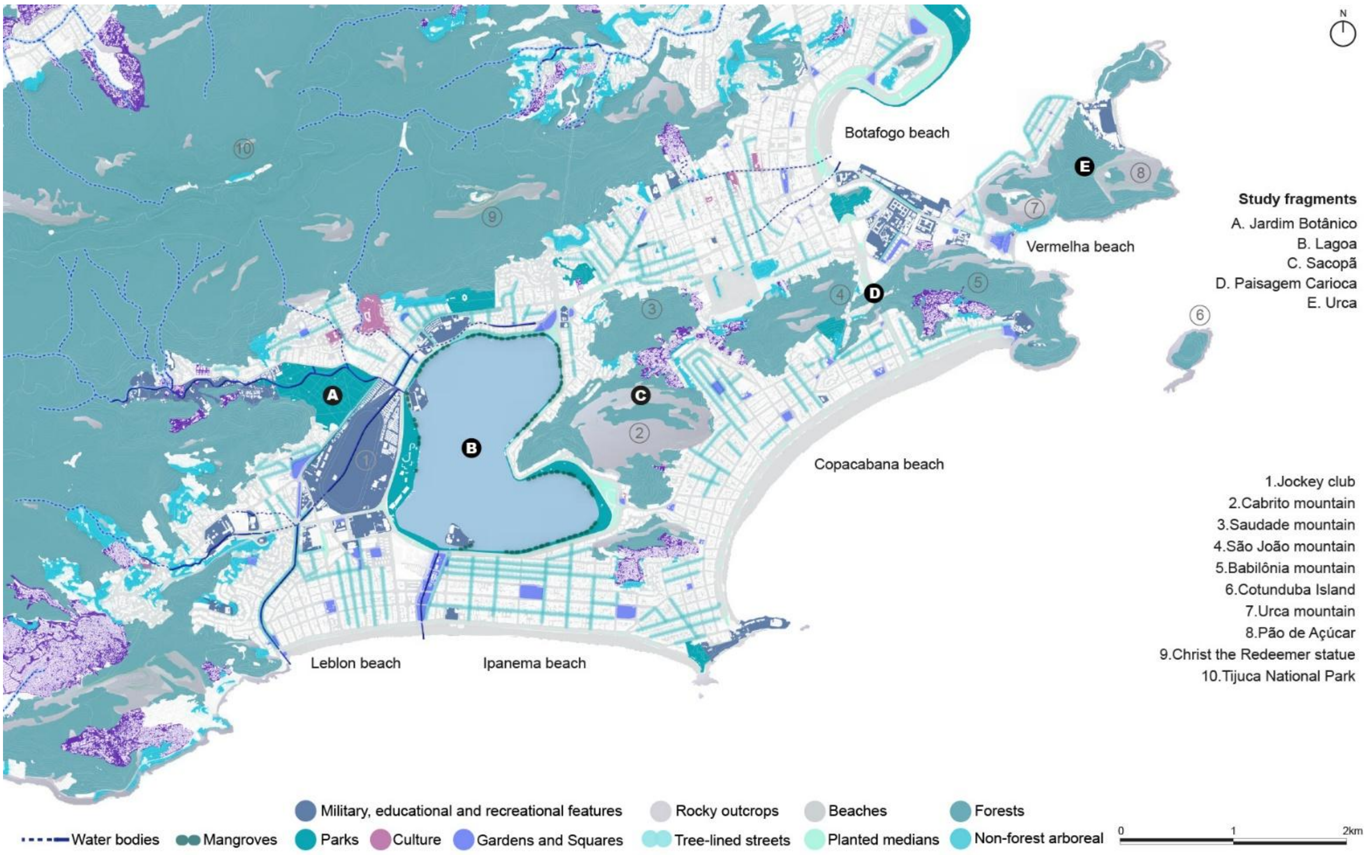
Blue–Green Networks

The study area encompassed forests, mangroves and other ecosystems associated with the Atlantic Forest biome. Although they have been deeply transformed by the sprawl of the city, dense ombrophilous forest remains around in fragments analyzed (Figure 3). The Tijuca Forest is the largest one, representing a hotspot of biodiversity in the green network. *Lagoa Rodrigo de Freitas* is a life-support system for animals and plants in the blue network. Although the lagoon border has been filled and suffered organic pollution (Alves; Pereira, 1998), ecological restoration initiatives have been launched for the mangroves.

Among urban green spaces (Figure 3), there are parks with both restricted access (e.g., the arboretum in *Jardim Botânico do Rio de Janeiro* (Botanical Garden of Rio de Janeiro, A) and unrestricted access (the edges of *Lagoa,* B) as well as squares and gardens that play strategic roles in ecological connectivity. Some municipal natural parks are not classified as so due to extensive forests therein (e.g., *Paisagem Carioca,* D). Green spaces associated with planted median are shaped by lawns and trees, especially around *Lagoa* and the surrounding neighborhoods. Tree-lined streets contribute to the concentration of green areas, although they do not always form continuous corridors.

The green spaces associated with military, educational and recreational features are the largest, such as the university campuses and the military areas around *Urca* (E). Green spaces associated with cultural facilities are generally linked to heritage buildings. Finally, non-forested arboreal vegetation, composed of dense masses of trees lacking explicit spatial organization, is found in formal and informal settlements as well as vacant urban spaces in different neighborhoods.

Figure 3 - Blue–green networks

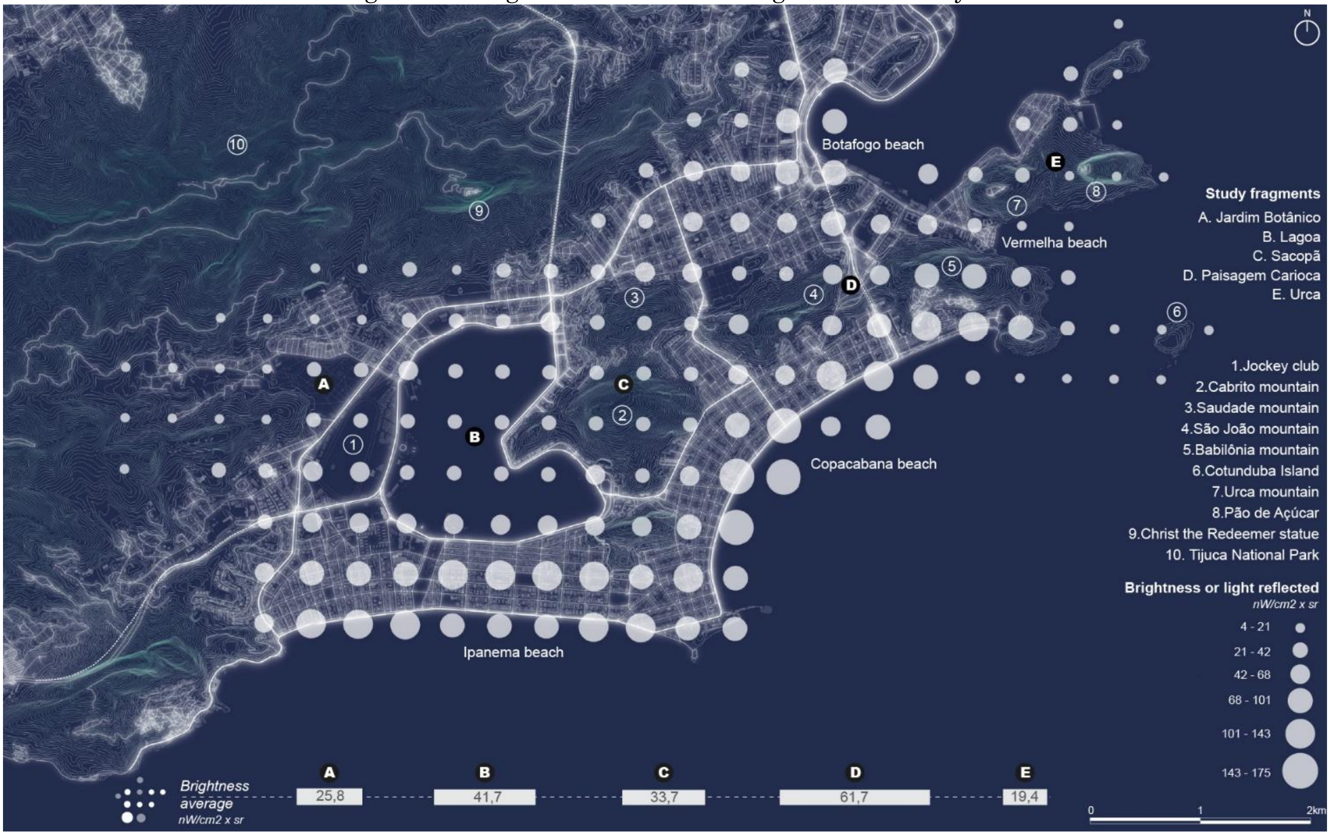


Source: The authors (2025), from vegetation cover and land use 2018 and 2019 (IPP, 2021).

Brightness and Reflected Light

Looking at the city from above at night, the forests are the darkest areas in the landscape. However, they are not necessarily free from direct or indirect lighting, whether it comes from human presence inside the forest or at its perimeter, or from the lit roads that cross their boundaries. *Paisagem Carioca* (D) has the highest average reflected light value (61.7) and the greatest variation. Next is *Lagoa* (B, 41.6), followed by *Sacopã* (C, 33.7). *JBRJ* (A) and *Urca* (E) have the lowest radiance indexes, averaging 25.8 and 19.4, respectively (Figure 4).

Figure 4 - Brightness or reflected light in the study area



Source: The authors (2025), from "Radiance light trends" (Stare; Kyba, 2019).

This paper reveals negative aspects of the recent implementation of light-emitting diodes (LEDs) in Rio de Janeiro: higher light levels, higher color temperature (extremely white) and a broader light spectrum. Besides the visual discomfort, these sources have broad environmental impacts, and their impact on biodiversity was not considered, according to interviews with architects, astronomers and lighting designers. The interviewees also highlighted the lack of public policies regulating light ecological pollution in conservation units and the need to expand environmental considerations beyond energy efficiency.

Sensitivity of Fauna and Flora at Night

JBRJ (A), a green space associated with urban parks, has the highest number of environmentally sensitive species (56), mostly in forested areas. *Urca* (E) comes second (24), followed by *Sacopã* (22). *Lagoa* (B) and *Paisagem carioca* (D) have the fewest sensitive species (5 and 21, respectively), demonstrating the predominance of species with more plasticity (Figure 5).

Among the most sensitive non-flying mammals, we highlight those most dependent on forests, such as *Cuniculus Paca* (Rios *et al*., 2022), the hedgehog *Coendou spinosus* (Cassimiro *et al*., 2023) and the opossums *Caluromys philander* and *Metachirus nudicaudatus* (Reis *et al*., 2011). The raccoon *Procyon cancrivorus* and the armadillo *Dasypus novemcinctus* prefer open areas, but they are semi-forest-dependent (Cassimiro *et al*., 2023).

Figure 5 - Environmental sensitivity: explorations of ecological connectivity at night

Source: The authors (2025), from appendix 11 Ferreira (2024).

Among the bats, 12 species are relatively rare because they are uncommon and non-generalists (Pires; Cadermatori, 2018). For example, *Eptesicus brasiliensis*, an insectivorous bat, flies more slowly and forages in background cluttered spaces (Reis, 2019). *Lonchophylla peracchii* is not classified as a rare bat but is endemic in the Atlantic Forest (Quintela *et al.*, 2020). *Vampyressa pusilla* is a relatively common non-generalist bat (Pires; Cadermatori, 2018).

Owls, such as *Pulsatrix koeniswaldiana* and *Asio clamator*, are indicators of environmental quality, as they are more specialized, according to the interviewed ornithologist Aloysio Moura. *Aramides cajaneus*, associated with open areas and forests, is highly sensitive bird (Stotz *et al.*, 1996), and collisions of this species with lit windows have been recorded during its night flights (Sick, 2001). *Falco peregrinus* bird is a visitor from the Northern Hemisphere (Pacheco *et al.*, 2021) that exhibits moderate sensitivity to habitat disturbances (Stotz *et al.*, 1996).

Of the most sensitive plant species, 25 are endemic and native (e.g., the palm tree *Astrocaryum aculeatissimum*), and four are threatened. The palm tree *Syagrus Picrophylla* is endemic and native and is classified as vulnerable (CNC Flora, 2012). In contrast, the tree *Lecythis pisonis*, found in *JBRJ* (A) and Sacopã (B), is not considered threatened, but it is an endemic and native tree with a specific feeding interaction with the bat *Phyllostomus hastatus*.

We highlight more sensitive animals that only were identified in certain fragments, indicating lower ecological connectivity (Figure 4, bottom). Most are in *JBRJ* (A): the bird *Tigrisoma lineatum* is classified under medium sensitivity (Stotz *et al.*, 1996). Eight non-flying mammals are dependent on forests, such as the anteater *Tamandua tetradactyla*, the marsupial *Metachirus nudicaudatus* and the rodent *Cuniculus paca* – that reacts to moonlight (Pereira *et al.*, 2016) - and is locally vulnerable (SMAC, 2022b). Although it resides in open areas and edges, the cottontail *Sylvilagus brasiliensis* is endangered by habitat loss (IUCN, 2023).

Almost all flying mammals—classified as rarer in urban environments—are situated in *JBRJ* (A), such as the bat *Chiroderma doriae*, which is locally vulnerable (SMAC, 2022b). The bat *Tonatia bidens* is found in tree hollows or forested areas (Reis *et al.*, 2007). The biologist Júlia Luz mentioned that a large abundance of this species, which had not been recorded in a city for a long time, was found in an archipelago nearby. In contrast, *Cerdocyon thous* is a mammal with greater plasticity found only in

JBRJ (A), indicating lower connectivity with terrestrial species. This may be due to the surrounding avenues that fragment the habitat.

Some birds were found only in *Urca* (E). *Actitis macularius* and *Vireo olivaceus* are both seasonal visitors from the Northern Hemisphere (Pacheco *et al.*, 2021). They are classified as having low sensitivity (Stotz *et al.*, 1996). However, as migratory birds, they can demonstrate greater sensitivity to urban lighting (Gauthreaux; Belser, 2006). Some bats classified as rare and non-generalist were only identified in this fragment (e.g., *Sturnira tildae de la Torre* and *Nyctinomops Macrotis*) and are selective in terms of habitat. The so-called "fisherman" bat, *Noctilio leporinus*—which usually forages in the lagoon and roosts nearby, according to the interviewed biologist Adarene Motta—was identified in *Lagoa* (B).

Some species were present in every fragment. The bat *Molossus molossus* forages in uncluttered spaces (Kalko *et al.*, 1996). This bat is an aerial insectivore characterized by narrow wings and high, fast flight. Due to these characteristics, this bat is less sensitive to lit areas, foraging under lights and quickly escaping from predators (Rydell, 2006). In contrast, *E. brasiliensis*, a slower-flying aerial insectivore bat, is negatively affected by urban lighting despite feeding on insects attracted to artificial light (Reis, 2019).

EXPLORING NOCTURNAL NETWORKS IN LANDSCAPES

Although *JBRJ* (A) is the smallest fragment, it is connected to the *Tijuca* Forest and crossed by rivers, which increases species richness. *JBRJ* does not have the lowest reflected light levels among the fragments but, during this study fieldwork, several fireflies were identified – which confirm high nocturnal environmental quality (Sordello *et al.*, 2018). The vegetation filters the brightness and maintains low light levels, although the edges are affected by street lighting. Given *JBRJ's* environmental importance, the surrounding urban lighting should be reviewed in terms of intensity, spectrum, color temperature and shielding.

Urca (E) is surrounded by less dense urban areas, and its boundaries touch the sea. The presence of migratory and nocturnal birds draws attention to strategic connectivity areas, such as *Vermelha* Beach, a potential green corridor between conservation areas (Figure 5). Managing lighting by shielding, reducing intensity, adjusting color and timing, and dimming lights during bird migration supports urban biodiversity. Lowering light levels in surrounding buildings during migration is also beneficial (Savard *et al.*, 2000).

Lagoa (B) and *Paisagem Carioca* (D) have the most reflected light and the fewest sensitive species. Most species in *Lagoa* (B) have high plasticity, but the bat *Noctilio leporinus* may suffer from habitat loss. *Paisagem Carioca* (D) has native trees that support nocturnal animals (e.g., *Pouteria bullata*). Parks with unrestricted access, such as *Lagoa* (B), must balance people and wildlife. Lagoon wetlands provide places for animals to rest, feed and nest (Alves; Pereira, 1998). To protect these areas, urban lighting around lagoons should use shielding, the lowest intensity, spectrum and color temperature.

The forest areas in the urban matrix are essential sources of biodiversity and help preserve darkness at night by remaining unlit (Gaston *et al.*, 2012). Its edges and immediate buffers adjacent should be priority in the nocturnal planning. However, they are permeated by light from both formal and informal settlements. The conservation units are inhabited: recently, the *Horto* neighborhood, located at the edges of the *Tijuca* Forest and *JBRJ*, implemented LED lighting. Urban lighting is crucial for accessibility and mobility at night, but light sources from these settlements should have shielding, lower intensity, and color temperatures as they get closer to forested areas.

Furthermore, coastal areas are highly exposed to light pollution (Figure 4). Although urban beaches have undergone many changes and no longer house the original ecosystems, there are relevant nesting areas for nearby seabirds. Skyglow generated by city lighting can indirectly impact these animals, as astronomers noted in interviews. The proximity of protected places could serve as a standard for choosing urban lighting in beach zones. Therefore, decreasing intensity, light beam extension and color temperature is fundamental.

Squares and gardens are green spaces with unrestricted access, and their maintenance requires a greater balancing between social and ecological considerations. Squares are thought to host species with greater plasticity. However, they can still play a role as steppingstones for nighttime connectivity. Urban lighting should be redesigned, particularly in squares close to forests, where it is essential to balance nocturnal biodiversity and the spatial quality of the urban experience.

Some green spaces associated with recreational features are private, but they might also contribute to nighttime connectivity. For example, the Jockey Club is a large, open green space placed between the Lagoon and the Botanical Garden of Rio de Janeiro. Nevertheless, its current lighting is excessive, with LED floodlights used on training and competition days. Time regulation, shielding, reduction of source intensity and reduction of color temperature should be considered in these spaces.

Many green spaces have heritage buildings and monuments illuminated at night to highlight the city's image. Since these areas can connect habitats, the timing and intensity of lighting must be reviewed. The closer they are to forests, the stricter the regulations should be. For example, the Christ the Redeemer statue at Tijuca Forest is always lit at night, attracting many insects since the 1970s (Jornal do Brasil, 1973). Although the impact has been reduced, as an interviewed ICMBio biologist argued, it is still important to review the timing, color temperature, spectral characteristics and intensity of the lighting.

Planted median that are not frequently used should be less illuminated. Similarly, non-forested arboreal vegetation areas should remain unlit. Tree-lined streets can contribute to connectivity by creating linear corridors or acting as steppingstones (Farinha-Marques *et al.*, 2017). However, depending on the traffic, these roads may present obstacles to some animals. Moreover, the lighting along roads can reduce connectivity at night for certain species, depending on their plasticity. In this sense, the closer to environmental areas, the lower color temperature, spectral characteristics and intensity of the street lighting should be.

Expert interviewees discussed how bats can move between habitat fragments, but the urban matrix can limit this movement. Some interviewed biologists emphasized the need to consider different landscape scales. Local scales can reveal species with greater plasticity in the urban environment, while broader scales highlight more specialized organisms. For example, the endangered bat *Myoris ruber*, which lives in Tijuca Forest, was not found in the fragments analyzed, suggesting reduced connectivity through the city. Nevertheless, species with greater plasticity in urban environments also can serve ecological functions as pollinators, seed dispersers (e.g., frugivores or omnivores), or population controllers (e.g., insectivores and carnivores).

Other guidelines have been proposed for stimulating nocturnal networks, such as turning off urban lighting on sidewalks - which would be hardly acceptable in our sociocultural context -, maintaining only lights from stores or signs and implementing lower color temperatures, ideally between 1500 and 2400 k (Sordello *et al.*, 2021). Considering the flowering and fruiting seasons of plants, a more adaptable urban landscape design should integrate different levels of light, which may be switched off or dimmed based on the lifecycles of animals and plants (Gaston, 2012), thereby reinforcing interspecific interactions at night.

Despite these findings, this research has limitations. The biodiversity survey may have neglected many species. This absence of species may be due to limited nocturnal sampling efforts or differences in the methods applied in the analyzed studies. Acoustic monitoring for bats tends to be more efficient for identifying species than conventional methods such as mist nets (according to bat specialists interviewed). Therefore, the analyzed fragments may not include certain high-flying bats (e.g., other aerial insectivores).

Additionally, some nocturnal bird species are neglected due to the difficulty of identifying them and the lack of nighttime fieldwork. Consequently, they are excluded from public environmental policy (Moura *et al.*, 2020). The owl *Asio clamator* has been found only in *Paisagem carioca* (D), but it is unclear whether this is due to lower connectivity or limited nocturnal sampling efforts. Other factors can reduce ecological connectivity, such as urban density, also, the promotion of biodiversity requires the provision of food, water and shelter in green spaces, as they allow animal movement through such spaces – according to some interviewed biologists.

The collection of nighttime satellite data was the most exploratory stage of this research. In addition to the satellite's spectral range being less sensitive to the spectrum emitted by white LED lights, the radiance of a selected area is the sum of individual pixels and is not measured by area, which may lead to a higher average light value, such as in *Paisagem Carioca* (D). Conversely, the scale of the biodiversity analysis was expanded, which would not have been feasible with ground-based point measurements alone (Hölker *et al.*, 2021).

Finally, the proposed guidelines face significant sociocultural and instrumental challenges to their implementation due to the absence of light pollution public policies and the complex relationship between light and security, especially in contexts of socio-spatial inequalities. On the other hand, there are debates that criticize the effectiveness of lighting as an isolated instrument of public safety (Thompson *et al.*, 2023). Furthermore, we believe in reconciling the uses and functions of open spaces with lighting guidelines, which should be implemented gradually, taking into account the proximity of environmentally sensitive areas. It is essential to establish participatory and interdisciplinary processes, as well as to consider the nocturnal ecological network beyond administrative boundaries (Challéat *et al.*, 2021; Berger; Quadu, 2025).

FINAL CONSIDERATIONS

The combination of fieldwork, interviews and bibliographic research in this study enabled an interdisciplinary analysis of the connections between blue–green networks and nocturnal habitats as well as their relationships with the urban environment. This interdisciplinary approach integrated data and methods from different fields of knowledge, using cartography as the central tool. The generated maps report biodiversity, green spaces and brightness data at different scales of territory, highlighting nocturnal biodiversity in the study area and its environmental sensitivity estimated.

The exploration of this nocturnal ecological network does not run out the mapping of other urban green spaces and its nocturnal biodiversity. On the contrary, it highlights the importance of further studies on nocturnal fauna and the effects of artificial lighting on Brazilian tropical habitats. Certain features are common across urban lighting guidelines for each type of green space, such as color, timing, spectrum and source intensity. These exploratory guidelines can contribute to more sustainable and less rigid planning for urban lighting, foregrounding the relevance of different scales of open spaces and associated socioecological networks.

Following previous research suggestions (Challéat *et al.*, 2021; Sordello *et al.*, 2021; Berger; Quadu, 2025), this paper seeks to integrate the nocturnal dimension into the urban agenda, thereby encouraging improved guidelines for urban lighting and expanding the debate on biodiversity beyond conservation units. We understand city lights through a relational approach through the landscape—a perspective that acknowledges the coexistence between humans, fauna and flora in the nocturnal landscape of the city.

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Tatiana de Albuquerque Ferreira: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft and Writing – review & editing.
Lúcia Maria Sá Antunes Costa: Writing – review & editing.
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