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MORALITY BEFORE KNOWLEDGE

The impact of Artificial Light at Night (ALAN) on biodiversity: Flora and fauna at Kebun Raya Bogor

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ABSTRACT
Background: Artificial light at night (ALAN) poses significant ecological challenges by altering the natural light environment. Plants and animals have evolved to depend on natural light cycles for their physiological and behavioral processes. This study investigates the impact of ALAN on the biodiversity of flora and fauna at Kebun Raya Bogor (KRB), a key site for understanding these effects. **Methods:** This research employs a literature review approach to analyze the effects of ALAN on flora and fauna. By examining existing studies and data, the review focuses on changes in plant physiology, including photosynthesis and growth patterns, as well as alterations in animal behavior, such as foraging, mating, and migration. The review synthesizes findings from various sources to assess the impact of ALAN on biodiversity at KRB. **Results:** Findings indicate that ALAN disrupts plant photosynthesis and growth, particularly affecting deciduous trees and altering reproductive and growth patterns. For fauna, ALAN significantly impacts the behavior of nocturnal species such as bats and birds, affecting their feeding, mating, and migratory patterns. The disruption in natural light cycles due to ALAN leads to ecological imbalances and may compromise the biodiversity of KRB.

KEYWORDS: artificial light at night (ALAN); biodiversity; Kebun Raya Bogor (KRB)

1. Introduction

Botanical gardens, also known as botanical parks or arboretums, serve several fundamental purposes related to plant botany, research, and education. These gardens are collections of labeled plants maintained and arranged scientifically, open to the public for recreation, education, and research. They fulfill four primary functions: scientific research, recreation, botanical and horticultural education, and public landscape aesthetics. Botanical gardens feature a diverse range of plant collections that mimic natural ecosystems. They can model natural biodiversity due to their inclusion of plants and other organisms such as animals, fungi, bacteria, and viruses. The collections in botanical gardens have the potential to serve as instruments for biodiversity research, functioning as small-scale natural ecosystems studied through ecological science due to their soil, water content, and specific organisms (Faraji & Karimi, 2022).

Indonesia ranks second globally for terrestrial biodiversity and first when aquatic biodiversity is included. The country faces the highest threat levels and extinction rates for plant species worldwide due to rapid deforestation and ongoing habitat degradation. Currently, Indonesia is home to several threatened animal species, including 191 mammals, 33 birds, 33 amphibians, 30 reptiles, 231 fish, 63 mollusks, and 26 butterfly species.

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Additionally, Indonesia hosts seven world bee species, with two species found only in the country and facing extinction. Conservation efforts are crucial to protect endangered forests and plants, both in their natural habitats (in situ) and outside them (ex situ). Botanical gardens in Indonesia primarily function as ex situ plant conservation sites, serving as a last bastion in efforts to save Indonesia's flora, particularly those that are rare, endangered, and endemic. The Bogor Botanical Gardens (KRB) currently houses 9,201 living plants in various forms, including herbs, shrubs, vines, and trees. The tree collections at KRB, some over 60 years old, consist of 1,496 trees from diverse families, each with unique and varied appearances and morphologies (Rachmadiyanto et al., 2021).

2. Methods

This paper employs a literature review approach, systematically examining existing studies and resources to build a comprehensive understanding of the topic. The process began with an extensive search for literature, aiming to identify sources that provide valuable insights and data. By carefully selecting and reviewing each source, the study ensures that only the most relevant and credible information contributes to its findings. This method allows the paper to present a well-rounded view, grounded in previous research and established theories, to support its analysis.

The core of this approach involves leveraging search engines and digital databases to access a diverse range of academic journals, books, reports, and other reputable resources. This search strategy helps to uncover various perspectives on the topic, enriching the study with a broad base of information. By integrating findings from multiple sources, the literature review not only highlights key trends and gaps in the existing knowledge but also establishes a strong foundation for further research. This methodology provides a structured path for synthesizing information, which is essential for drawing accurate conclusions and making informed recommendations.

3. Results and Discussion

3.1 Controversies and suspension of the GLOW Kebun Raya program

Bogor Botanical Gardens (KRB) is located in the heart of Bogor City at an elevation of 235-236 meters above sea level, covering an area of 87 hectares, making it the largest botanical garden in Southeast Asia. The management of KRB, along with other botanical gardens in Indonesia, is overseen by the National Research and Innovation Agency (BRIN). As the managing body, BRIN maintains KRB's preservation and introduces new programs to attract visitors for educational tourism.

The COVID-19 pandemic impacted social activities across all sectors, including KRB, which temporarily closed and later reopened with visitor restrictions in accordance with the Community Activity Restrictions (PPKM) regulations. One new initiative launched by BRIN in collaboration with PT MNR (Mitra Natura Raya) is the "GLOW Kebun Raya" program, an evening botanical garden experience designed to be Indonesia's first and largest night botanical garden. This program features plant education through fictional flora and fauna narratives and KRB's history using projection mapping and artificial lighting, as illustrated in Figure 1.

Visitor enthusiasm for GLOW Kebun Raya was high, particularly among millennials. However, the program was halted in early November 2022 following a Forum Communication Forum (Forkopimda) meeting attended by community representatives and PT MNR, the managing entity. The suspension was due to a lack of consensus among researchers regarding the impact of artificial lighting and sound systems on KRB's biodiversity. Additionally, cultural experts criticized the program's ethics, arguing that KRB, with its two-century history, is a cultural heritage site that should be protected from excessive commercialization.

Fig 1. Projection mapping artificial light installation GLOW Kebun Raya
(Kumparan, 2022)

The temporary halt was implemented pending accurate research on the negative impacts on KRB's biodiversity and the need for further investigation by independent agencies. PT MNR and BRIN initially claimed that artificial lighting would not harm biodiversity or the ecosystem at KRB, citing research conducted from January to June 2022. They also noted that the GLOW Kebun Raya area covered only 3% of KRB's total 87-hectare area, located in non-collection sections of the garden, thus minimizing disruption (Detik Travel, 2022). However, the author disagrees with the management's claims, noting that according to the program zone map, only one program is located outside the main garden ecosystem. Furthermore, despite the management's assertions, the presence of GLOW Kebun Raya in any part of KRB—a conservation area comprising various garden ecosystems—would inevitably have a negative impact on its biodiversity and ecosystem.

3.2 Artificial lights at night (ALAN)

Artificial lighting, upon its initial introduction, was recognized for its biological impacts on the environment during nighttime. Preliminary observations indicated delays in leaf retention in trees near artificial light sources, which also attracted insects and birds as external light sources. Recently, artificial lighting, known as ALAN (Artificial Lights at Night), has been acknowledged as a significant anthropogenic pressure on the environment due to human activities. ALAN affects various biological aspects including individual trophic levels, populations or species, abundance, distribution, reproduction, mortality, dispersal, community composition, and ecosystem functions such as pollination and seed dispersal. The effects of ALAN extend across different environments (marine, freshwater, and terrestrial), habitats, and among microbes, fungi, plants, and animals (Gaston & Sánchez De Miguel, 2022).

Light induces a series of physiological processes in plants. Primary productivity is influenced by plant physiology and phenology, both of which are affected by ALAN, thereby impacting plant flow through higher trophic organisms in the food web (Cieraad et al., 2023). According to Sanders et al. (2018), in a mesocosm study, increased ALAN intensity resulted in higher plant biomass, which coincided with an increased abundance of aphids, a parasite with a more complex relationship with artificial light. Furthermore, Meijer et al. (2022) reported that the light spectrum composition during the day significantly affects light absorption efficiency and CO2 fixation as growth factors. During the day, vegetation in a natural canopy absorbs red light for photosynthesis and reflects far-red light, reducing the red:far-red light ratio under the canopy, which affects photoreceptors, shade signaling, and light competition among surrounding plants.

3.3 Impact of ALAN on flora biodiversity

According to Bennie et al. (2016), plants exhibit high sensitivity to light, including its wavelength. Plant responses to light can be identified through plant pigments functioning as photoreceptors. For example, cryptochromes respond to light with a spectrum intensity between 390–530 nm (blue-green), while phototropins respond to red light. One critical plant activity disrupted by ALAN is photosynthesis. Photosynthetically Active Radiation (PAR), occurring in the 400–700 nm light spectrum, results in the absorption of chlorophyll and carotenoid spectra. Generally, plants use light as an energy source for photosynthesis and employ other photoreceptors to detect environmental conditions, including day and night cycles and seasons. The photosynthetic system is also sensitive to nighttime light, leading to secondary pathways affected by artificial light on carbon fixation. The most apparent impacts of nighttime light installations on plants include leaf retention in deciduous trees, bud emergence in trees, stress, and induction of flowering, as well as the growth and inhibition of plant development.

Low-intensity and short-duration artificial lighting can impact plant physiology under controlled conditions. Plants use natural light to detect canopy positions, proximity to competitors, and day length, which also serves as a source of photosynthetic energy. Artificial lighting can disrupt photoperiod systems and trigger variations in growth and energy allocation, potentially affecting abundance, biomass, and species composition (Bennie et al., 2018). Increased intensity of artificial light can lead to increased dry weight production in grasses, alter seedling production, and modify photoperiods, irrespective of temperature or total flux, which can influence the initiation and rate of dry weight reproduction and leaf area expansion across various species. Affected mechanisms include phytochrome photoreceptors and the growth hormone gibberellin. Phytochromes are regulated by red and far-red light, so light bulbs emitting longer wavelengths cause plants to respond more quickly than broad-spectrum white light (Bennie et al., 2016).

3.4 Impact of ALAN on fauna biodiversity

Most animals perceive reflected light from objects as a primary method for gathering information about their environment, crucial for finding food, mates, and avoiding predation. An animal's visual system must adapt well to its habitat and activity patterns in terms of spectral sensitivity, light detection levels, and temporal resolution that reflects its environment. This is known through the trade-off between light sensitivity and temporal resolution; photoreceptors capable of detecting low light levels may not effectively represent the environment, leading animals to operate at higher light intensities. Consequently, increased artificial light use results in environmental implications that differ significantly from natural light and may not align with animal eye adaptations. This, in turn, impacts behavior, reproductive systems, mortality, and community composition in animals (Inger et al., 2014)

Pollution from artificial lighting can lead to behavioral and ecological changes in wildlife species. Evolutionary adaptations of organisms to light-dark cycles due to solar activity underpin these changes. Daily activity rhythms, sleep patterns, body temperature, hormone secretion, and gene expression are initiated by visible sunlight. Annual changes induced by photoperiods regulate mating seasons, molting, immune functions, and metabolic rates, thus artificial lighting impacts are often associated with shifts in biological timing. Artificial light can affect photoperiod effects, leading to changes in behavioral and physiological patterns in organisms. Broad-spectrum light, such as blue light, has been shown to affect various behavioral and physiological responses in animals (Dominoni et al., 2020).

Biodiversity at the Bogor Botanical Garden (KRB) also includes diverse fauna, which is impacted by the nighttime light installations from the GLOW Kebun Raya program. ALAN can affect animal behavior, particularly bird sleep patterns. ALAN significantly influences the sleep patterns of male birds, especially during the breeding season, as female birds sleep in nests while males sleep freely and are disturbed by nighttime light (Raap et al., 2018). Male and female birds need several weeks to develop testes and ovaries for functional sperm and egg production. Gonadal growth must start well before the estimated laying period. Photoperiods are easily predictable due to their minimal annual variation, causing birds to use extended day lengths in late winter and early spring as cues for gonadal growth stimulation (Dawson et al., 2001). The presence of ALAN can cause birds to perceive longer photoperiods, leading to the misconception that this occurs year-round. ALAN can mislead birds into accelerating their reproductive cycles, which may reduce their physical endurance related to delayed reproductive efforts (Titulaer et al., 2012)

Nighttime light pollution can affect the activity rhythms of diurnal and nocturnal species, with major implications for individual abilities, sexual selection, and reproductive success. One nocturnal species at KRB is bats, which are negatively impacted by increased nighttime artificial light. Bats play a crucial role in ecosystem functions, necessitating conservation planning to preserve these ecosystems (Kalka et al., 2008). A decline in bat populations can compromise essential ecosystem services, making conservation understanding crucial (Williams-Guillén et al., 2008).

The natural light-dark cycle is a critical factor influencing the circadian biological rhythms of organisms exposed to daily fluctuations in sunlight. The timing of bird emergence from roosts at night is influenced by sunset times, foraging activities, and moonlight, as well as the length of nights. Artificial light can affect bat behavior, including foraging and movement, emergence, roosting, breeding, and hibernation. ALAN can disrupt bat habitats by interfering with foraging areas or indirectly severing migration routes through illuminated areas (Stone et al., 2015). ALAN can also hinder female bat emergence by attracting abundant insects, which disrupts their reproductive capabilities (Azam et al., 2015). The biological impacts of ALAN in aquatic ecosystems are similarly significant, affecting invertebrate habitat, turtle nesting times, and zooplankton migration, which are crucial for global carbon cycles (Gaston & Sánchez De Miguel, 2022). Aquatic vertebrates commonly found at KRB, such as fish, amphibians, and lizards, have photosensitive cells on their skin that regulate lamprey migration, skin pigment distribution in fish and frogs, and reptile basking times (Falcón et al., 2020).

4. Conclusions

Artificial Light at Night (ALAN) significantly disrupts both flora and fauna at Kebun Raya Bogor (KRB). For plants, ALAN interferes with crucial processes such as photosynthesis and growth by altering natural light cues essential for physiological responses and phenological patterns. This disruption affects leaf storage, bud emergence, flowering, and overall plant growth, leading to shifts in species composition and energy allocation.

For fauna, ALAN impacts behavioral and physiological processes, particularly in nocturnal species like bats and birds. It disrupts sleep patterns, breeding behaviors, and migration routes, with significant consequences for reproductive timing and ecological interactions. These disruptions can reduce species resilience and overall biodiversity, highlighting the need for careful light management practices to mitigate the adverse effects of light pollution.

Author Contribution

All author contributed fully to the writing of this article.

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