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RESEARCH ARTICLE

NAVIGATING DARKNESS: A PROPOSAL FOR DARK INFRASTRUCTURE TO REDUCE LIGHT POLLUTION AND ENHANCE NATURE'S PATHWAYS

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Abstract

Background: Light has become a form of spatial barrier, much like a road or wall, that disrupts wildlife movement. Therefore, the study explores how dark infrastructure can be used to support nocturnal biodiversity movement across the fragmented urban district of Bonifacio Global City (BGC), Metro Manila, Philippines.
Aim: To propose a conceptual dark infrastructure in BGC to reduce light pollution and foster nocturnal movement.
Methods: Using QGIS, a geographic information system, several maps were created for analysis, including a biotope map, an ecological management map, and an ecological connectivity map of a selected sub-watershed unit surrounding BGC. Data for some of these maps were imported into the software from geoportal PH and light pollution map.info.
Results: The findings reveal that much of the sub-watershed unit requires creative and improvement strategies, such as establishing vegetation buffers and replacing traditional street lighting. Several nodes were subsequently placed and connected to create dark movement routes for nocturnal wildlife and navigate the previously glaring urban district.
Conclusion: Through a proposed dark infrastructure, it affirms that mitigating light pollution and enhancing ecological connectivity are not competing objectives but can be synergistically addressed through landscape architectural interventions. By treating landscapes as both light filters and habitat corridors, urban environments like BGC can be redesigned to support nocturnal biodiversity while preserving essential urban functions.

Introduction:-

Artificial light at night has become an overlooked environmental pollutant, altering natural ecosystems and disrupting biological rhythms. Urban districts, particularly those characterized by dense commercial development and extensive nighttime illumination, contribute significantly to skyglow, glare, and light trespass. These forms of light pollution not only degrade environmental quality but also function as spatial barriers, much like physical infrastructure, by interrupting nocturnal wildlife movement and fragmenting habitat networks.Bonifacio Global City (BGC), a highly illuminated mixed-use urban district in Metro Manila, presents a compelling case of thischallenge. While designed primarily for economic activity, its landscape produces intense nighttime luminance that interrupts

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ecological processes and isolates remaining vegetative patches. This raises a critical question: how can landscape architecture strategically mediate between urban illumination and ecological continuity, particularly at night?

This study proposes a dark infrastructure as an ecological network that filters artificial illumination while facilitating nocturnal ecological movement. By approaching landscape elements as both light buffers and habitat corridors, the research investigates how urban landscapes can be reconfigured to support ecological connectivity without compromising essential urban functions. Through biotope mapping, ecological management zoning, and connectivity analysis of a sub-watershed area surrounding BGC, the study identifies landscape-based interventions that restore dark ecological routes across an intensely lit urban fabric.

Objectives:-

- To review management strategies applicable to dark infrastructure
- To utilize ecological planning tools to analyze the chosen sub-watershedunit
- To propose a dark infrastructure frameworkto reduce light pollution and foster nocturnal movement

Review of Related Literature:-

Artificial light at night alters ecological processes and can function as a non-physical barrier to animal movement, especially for nocturnal taxa. Several empirical and review studies have established the scope of ecological light pollution, described how light intensity, spectrum, directionality, and timing affect organisms, and argued for landscape-scale mitigation methods. For example, Hale et al. (2015) argue that city lighting scenarios can create threshold conditions that prevent bats from crossing gaps in the urban matrix, effectively fragmenting movements and reducing connectivity. Likewise, broad reviews of mitigation approaches emphasize that solutions must be multi-scalar, combining technical lighting design with landscape planning and protected-area management (Jägerbrand&Bouroussis, 2021). These syntheses provide the conceptual grounding for treating darkness as a design variable that can be shaped by vegetation, lighting controls, and zoning to support nocturnal movement.

Review of management strategies:-

Create (establish new habitat and dark corridors). Landscape interventions that create new vegetative structure and dark corridors are supported by studies showing that restoring or establishing vegetation at the urban edge can reduce the ecological impacts of illumination and provide movement habitat. Haddock et al. (2019) demonstrated that artificial lighting at urban forest edges reduces activity of insectivorous bats and decreases the effective habitat available to light-sensitive species, which implies that establishing vegetated buffers that screen and intercept light can expand usable habitat and re-open movement routes. Similarly, Barba et al. (2023) demonstrate that dense, continuous tree canopies with minimal gaps and sufficient height serve as movement corridors, increasing both species diversity and activity within illuminated urban contexts. Additional findings from Melbourne reveal that open green spaces embedded within areas of higher tree density and lower road density support greater bat presence, emphasizing the ecological value of creating strategically located vegetated buffers that filter light and reconnect habitat (Callas et al., 2024). Together, these studies show that creating new green corridors, buffers, and patches with deliberate canopy structure and connectivity can both shield landscapes from intrusive lighting and reestablish ecological movement routes for light-sensitive species.

Improve (retrofit and upgrade existing sites and lighting). There is growing evidence that targeted lighting retrofits and species-sensitive lamp choices can substantially reduce ecological harm while retaining human-oriented functions. Reviews of practical mitigation recommend full cutoff fixtures, dimming schedules, motion activation, and spectral management, such as using lower correlated color temperatures to reduce shorter wavelength, blue-rich output that is particularly disruptive to many taxa (Longcore et al., 2023; Jägerbrand&Bouroussis, 2021). Empirical work also shows that converting broad-area, constant illumination to adaptive systems reduces continuous light exposure and can restore temporal dark windows critical for nocturnal behaviors. In urban conservation contexts, these retrofit strategies are often coupled with habitat enhancement measures, such as those highlighted in other management categories, so that improved lighting does not simply move the problem to adjacent spaces.

Integrate (link green infrastructure and lighting design across land uses). Research that bridges landscape connectivity and lighting design supports integrated approaches that pair vegetative networks with adaptive lighting zoning. Hale et al. (2015) provide experimental evidence that light intensity and spatial configuration influence whether animals will cross open spaces, indicating that continuity of low-light corridors is necessary to maintain movement. Policy and guidance briefs advocate for multi-zone lighting strategies that deliberately create dark corridors or reduced-illumination buffers along waterways, greenways, and street-side vegetated strips so that connectivity is maintained through mixed-use districts (Interreg North Sea Region, 2023). In addition, reviews of green roofs and façades emphasize their potential to function as elevated connectivity nodes when they are strategically located and managed, and they recommend integrating lighting controls to avoid creating artificial islands of light that would negate habitat function (Mihalakakou et al., 2023). This body of work supports integrated tactics such as time-controlled façade lighting, green roof networks, and lighting zoning that preserve continuous low-illumination paths for nocturnal species.

Preserve (protect existing dark habitats and mature vegetation). Conservation-oriented literature emphasizes the importance of protecting remaining dark refugia and mature habitat nodes because these areas often host vulnerable or specialist species and act as keystone stepping stones in urban networks. Jägerbrand and Bouroussis (2021) recommend classifying sensitive habitats and applying more constrained lighting principles within and around them, while case studies and reviews of bats and other nocturnal taxa show that preserving undisturbed dark corridors or exclusion zones can maintain foraging and commuting routes that would otherwise be lost to encroaching illumination (Zielińska-Dąbkowska et al., 2021; Haddock et al., 2019).

Synthesis:-

The emerging literature indicates that restoring nocturnal ecological connectivity in brightly illuminated urban districts requires a coordinated suite of landscape and lighting interventions rather than isolated measures. Studies consistently show that structurally complex vegetation, strategically deployed across fragmented urban fabrics, can buffer artificial illumination while expanding habitat and facilitating movement for light-sensitive species. At the same time, research on lighting technologies and spatial planning demonstrates that modifying existing luminaires, reorganizing illumination patterns, and embedding ecological logics into corridor design can substantially reduce the disruptive effects of skyglow and glare on wildlife. Equally important are governance-oriented approaches that safeguard remaining dark refuges, ensuring that the ecological gains produced by new plantings and lighting retrofits are not undermined by future development. Taken together, these findings affirm that nocturnal connectivity is best achieved through an integrated landscape framework that combines habitat creation, system improvement, spatial integration, and long-term protection. Such an approach reframes darkness as an intentional design resource capable of reconfiguring urban environments into more permeable, ecologically responsive networks.

Materials and Methods:-

The study utilized QGIS, a geographic information system, to create various maps for analysis. The data in some maps was imported to the software from geoportal PH and lightpollutionmap.info. It is acknowledged that there are limitations of the utilized light pollution data. According to Mander et al. (2023), VIIRS/DNB satellite, such as the one used in this study, suffers from poor spectral resolution and that there is yet for an instrument that can accommodate cost, ease of use, data, and spectral range.Nonetheless, the data gathering process began with identifying a suitable sub-watershed unit encompassing BGC.Mapping procedures were then conducted to determine the soil characteristics, slope conditions, and land cover within this unit. These datasets formed the basis for developing a biotope map, which was subsequently categorized according to area, period of development, rarity, habitat type, and levels of light pollution. This was further supported by a value assessment matrix and a set of assessment criteria. Collectively, these components informed the preparation of the ecological management map and the ecological networking map.

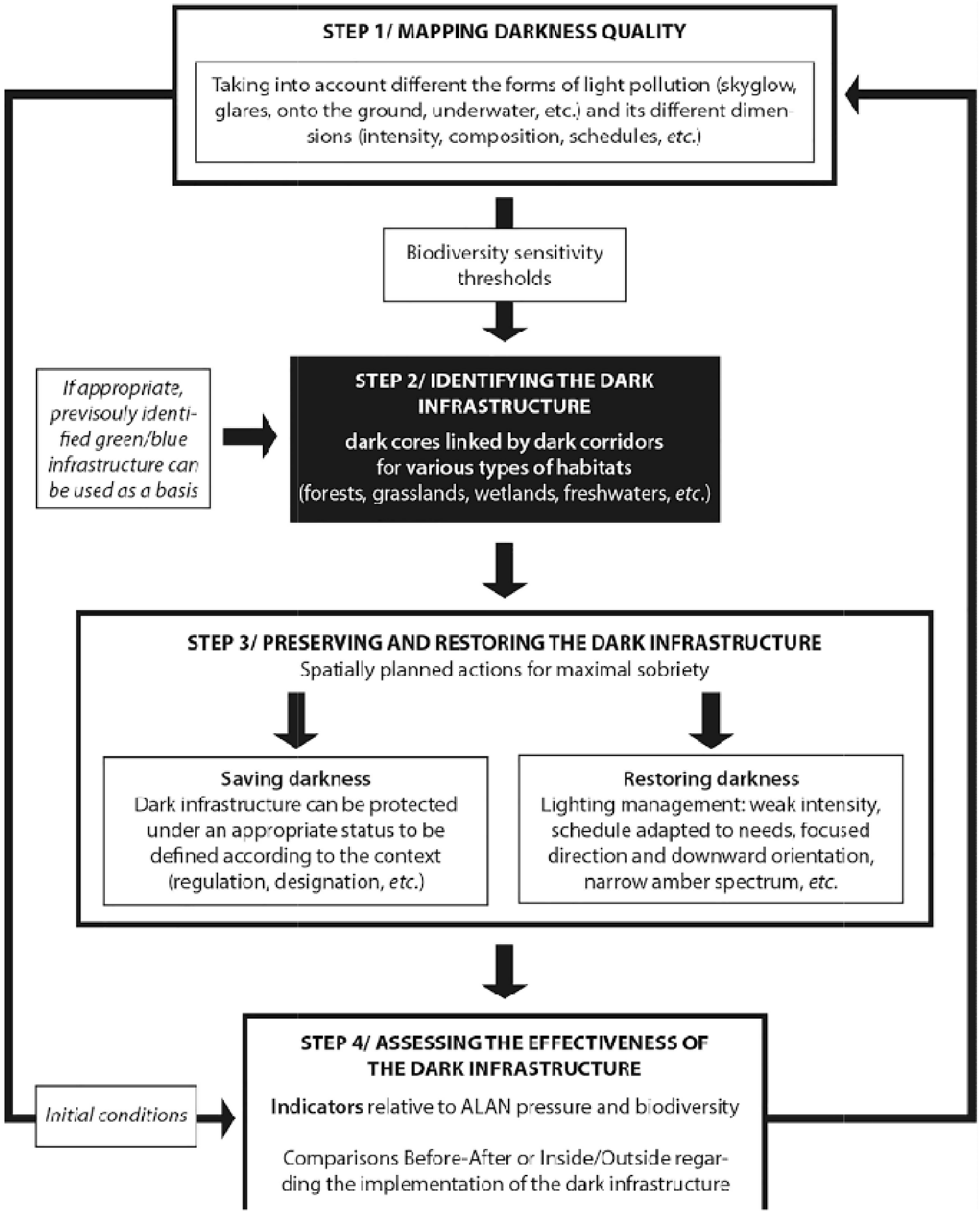

Figure 1: Four-step process to identify, preserve, and restore dark infrastructure
Source: Sordello et al. (2022).

In the development of a dark infrastructure in the final map, this research adapts the four-step process of Sordello et al. (2022): mapping darkness, identifying dark infrastructure, preserving and restoring dark infrastructure, and assessing the effectiveness of dark infrastructure. While this is taken into account, it is not strictly followed in this research when it is inapplicable. For instance, step four is not performed because it requires comparisons before and after the implementation of the dark infrastructure. However, since this research only reaches a conceptual level, assessing the effectiveness of the dark infrastructure is not possible.Therefore, the study carefully interprets its findings and acknowledges that the data are limited to a conceptual level.

Results:-

Watershed map. The map situates the study area in BGC within its broader watershed system. The selected sub-watershed and its drainage channels illustrate how surface water moves across the urban landscape. Sub-watershed and main watershed boundaries provide a spatial basis for integrating landscape interventions with existing hydrological patterns.

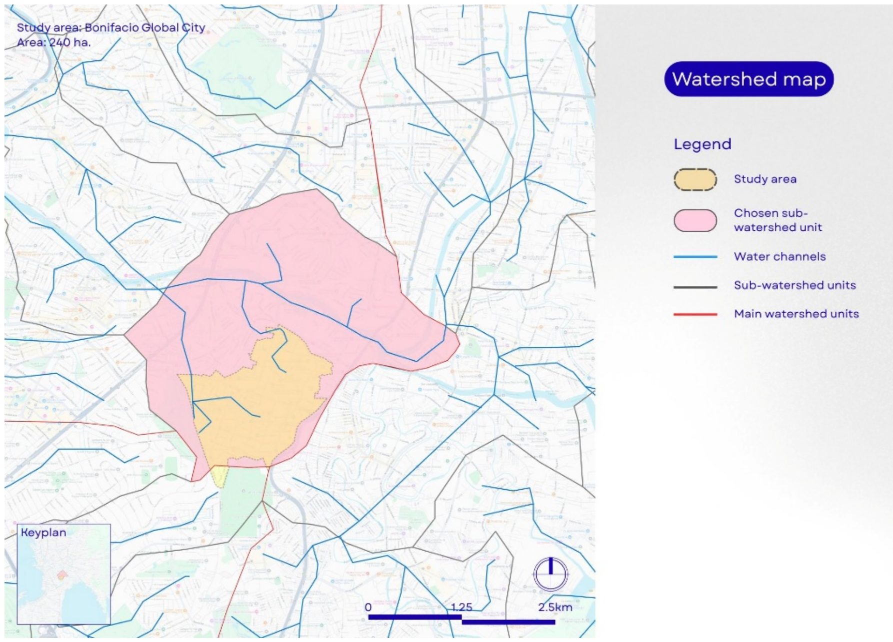

Figure 2. Watershed map

Biotope map. The biotope map is derived by intersecting three maps: soil, slope, and land cover. It reveals 125 unique biotope typesand highlights ecological character that can provide a basis for identifying areas suitable for various interventions.

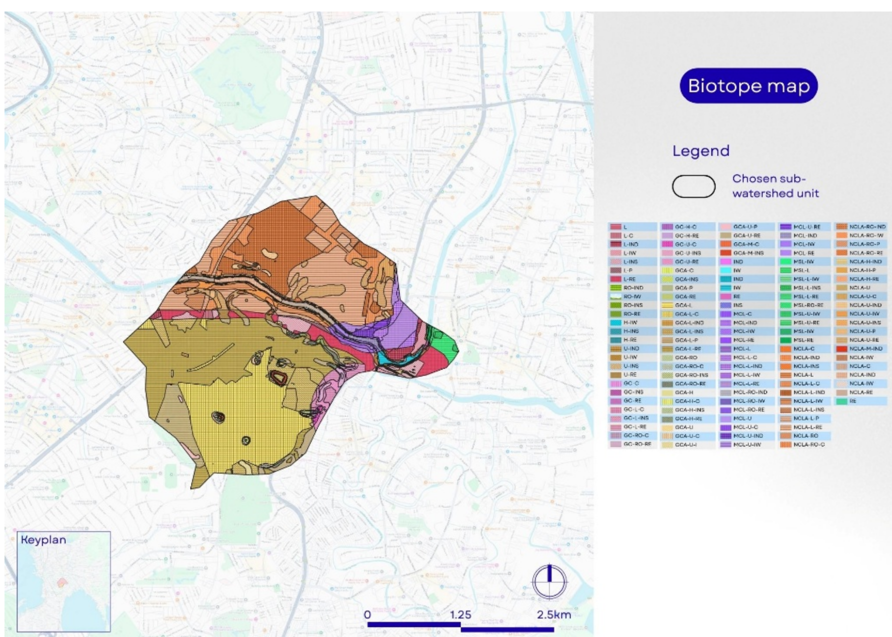

Figure 3. Biotope map

Ecological management map. Using the biotope map, the sub-watershed is categorized into its area, period of development, rarity, habitat, and light pollution. Each of these variables are further grouped into five categories.

1. A0 (0-5 ha), A1 (5–10 ha), A2 (10–20 ha), A3 (20–30 ha),A4 (30–178 ha)
2. D0 (<=5 years), D1 (5-10 years), D2 (10-20 years), D3(20-30 years), D4 (>30 years)
3. R0 (Many similar biotopes occurring in the site, nearest equivalent is 1 to 1000 meters away), R1 (Several similar biotopes in the site, the nearest equivalent 1000 to 2000 meters away), R2 (The nearest equivalent biotope over 2000 meters away, or only approximately six to ten corresponding biotopes in the site), R3 (Only one to five corresponding biotopes in the site), R4 (No equivalent biotopes in the site)
4. H0 (Almost exclusively grass or trampled ground), H1 (Almost exclusively a uniform vegetation other than grass or trampled ground), H2 (Two different vegetation structures), H3 (Three different vegetation structures), H4 (Four different vegetation structures).
5. L0 (>100), L1 (75-100), L2 (50-75), L3 (25-50), L4 (<=25). *Measurement of radiance 10-9 W/cm2 * sr(based on VIIRS)

This gives more robust data in assessing the value of each biotope unit. Specifically, the value assessment matrix and assessment criteria are as follows.

Value assessment matrix

Area (A)	Period of Development (D)	Rarity (R)	Habitat (H)	Light Pollution (L)	Value
A0	D0	R0	H0	L0	1
A1	D1	R1	H1	L1	2
A2	D2	R2	H2	L2	3
A3	D3	R3	H3	L3	4
A4	D4	R4	H4	L4	5

Assessment criteria

Rating	Management Approach
5-9	Creative Management
10-14	Improvement Management
15-19	Integrative Management
20-25	Preservation Management

Figure 4. Value assessment matrix and Assessment criteria

Each biotope unit is evaluated and assigned a corresponding management strategy: create, improve, integrate, or preserve. The following map visualizes this.

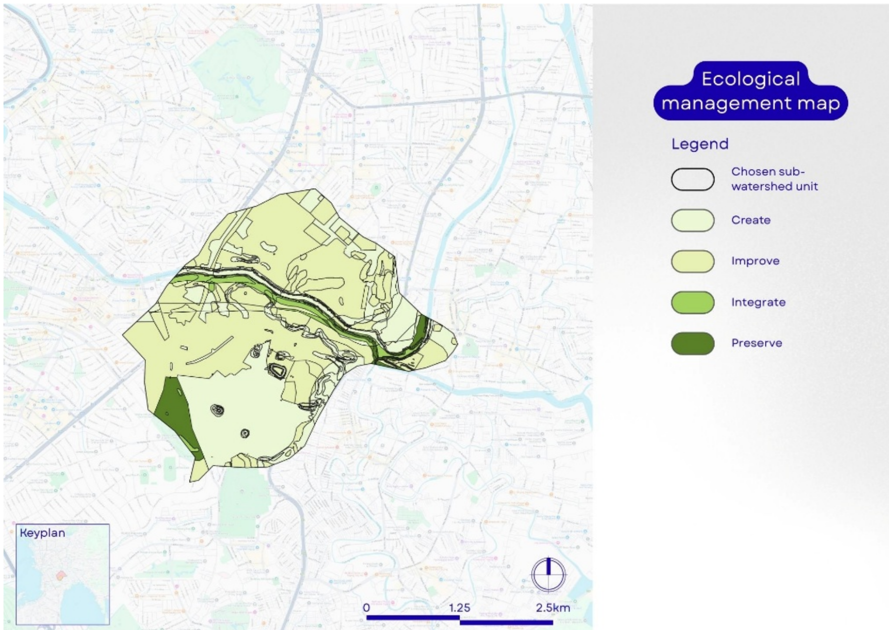

Figure 5. Ecological management map

Discussion:-

Management strategies. Through the review of related literature, the specific management strategies are proposed to reduce light pollution and enhance habitat connectivity.

Figure 6. Management strategies

Ecological networking map. Nodes and corridors are identified. Nodes are small, higher-quality habitat patches—such as parks, tree clusters, or vegetated setbacks—that provide food, shelter, or refuge. Corridors are linear pathways connecting these nodes, including tree-lined streets, vegetated walkways, shaded edges, or darker routes that reduce light and disturbance. Together they form a network that enables wildlife movement through dense urban environments, with nodes tied to different management strategies.

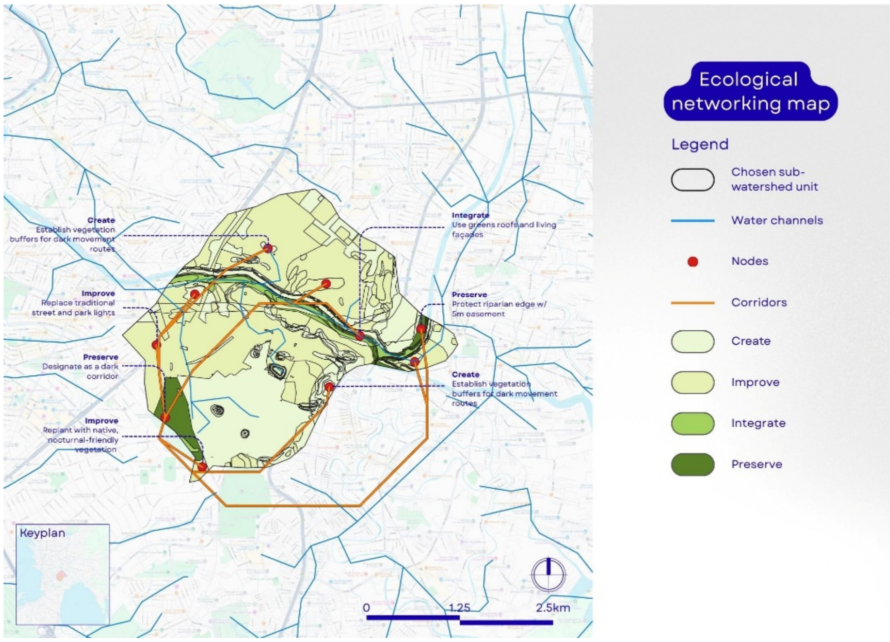

Figure 7. Ecological networking map

Ecological networking map with light pollution map. Nodes are selected based on local light pollution, prioritizing L2–L4 areas, and connected to form dark routes for nocturnal wildlife. Corridors are generated using a least-cost path analysis that identifies the least light-polluted connections between nodes, following Hu et al. (2021). For example, the bottom-right corridor extends beyond the sub-watershed to maintain a darker path rather than connect directly to the next node.

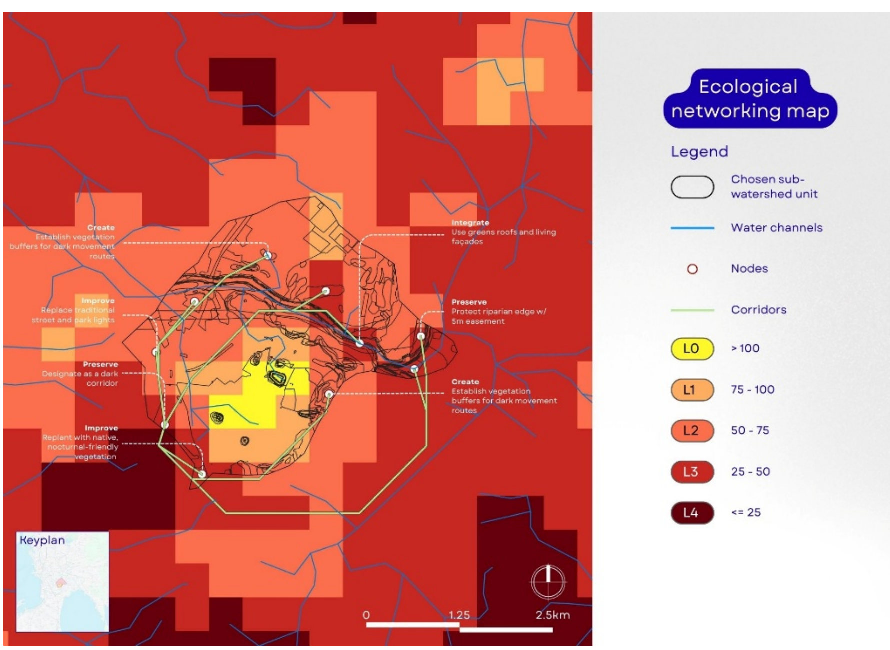

Figure 8. Ecological networking map with light pollution map

Conclusion:-

This study demonstrates that artificial illumination in BGC functions not only as an environmental pollutant but also as a spatial barrier that fragments ecological networks and obstructs nocturnal wildlife movement. Through a proposed dark infrastructure, the research conceptually highlights the potential of landscape architecture to mediate between urban illumination and ecological continuity.Through biotope mapping, ecological management zoning, and connectivity modeling, the study reveals that most of the sub-watershed surrounding BGC require creative and improvement strategies, indicating substantial room for ecological enhancement through vegetative buffering, adaptive lighting retrofits, and the establishment of nocturnal corridors. The placement and linkage of nodes across the urban fabric demonstrate how dark ecological routes can be intentionally shaped to reconnect fragmented habitats, even within high-luminance districts.

Ultimately, the findings affirm that mitigating light pollution and enhancing ecological connectivity are not competing objectives but can be synergistically addressed through landscape architectural interventions. By treating landscapes as both light filters and habitat corridors, urban environments like BGC can be redesigned to support nocturnal biodiversity while preserving essential urban functions. This positions intentional darkness as a viable tool in ecological urbanism—an approach that views light not only as infrastructure but also as a material for spatial control, ecological influence, and design agency.Moving forward, the development of dark infrastructure should be further studied just as it has been with its blue-green infrastructure counterpart. According to Sordello et al. (2022), most international conservation strategies take little to no account of darkness. Hence, it is hoped that future research can likewise take more interest in this topic.

References:-

1. Barba, M. D. O., Lavy, B. L., & Bennett, V. J. (2024). Improving urban flyways for bats: the importance of tree canopy structure. Wildlife Biology, 2024(5), e01284.
2. Callas, M., Lumsden, L. F., Rendall, A. R., &Yokochi, K. (2024). More trees and fewer roads: the importance of local and landscape features for insectivorous bats in open urban green spaces. Wildlife Research, 51(4).
3. Haddock, J. K., Threlfall, C. G., Law, B., & Hochuli, D. F. (2019). Light pollution at the urban forest edge negatively impacts insectivorous bats. Biological conservation, 236, 17-28.
4. Hale, J. D., Fairbrass, A. J., Matthews, T. J., Davies, G., & Sadler, J. P. (2015). The ecological impact of city lighting scenarios: exploring gap crossing thresholds for urban bats. Global change biology, 21(7), 2467-2478.
5. Hu, J., Liu, Y., & Fang, J. (2021). Ecological corridor construction based on least-cost modeling using visible infrared imaging radiometer suite (VIIRS) nighttime light data and normalized difference vegetation index. Land, 10(8), 782.
6. Jägerbrand, A. K., &Bouroussis, C. A. (2021). Ecological impact of artificial light at night: effective strategies and measures to deal with protected species and habitats. Sustainability, 13(11), 5991.
7. Korpach, A. M., Garroway, C. J., Mills, A. M., von Zuben, V., Davy, C. M., & Fraser, K. C. (2022). Urbanization and artificial light at night reduce the functional connectivity of migratory aerial habitat. Ecography, 2022(8), e05581.
8. Longcore, T. (2023). Effects of LED lighting on terrestrial wildlife.
9. Mander, S., Alam, F., Lovreglio, R., & Ooi, M. (2023). How to measure light pollution—A systematic review of methods and applications. Sustainable Cities and Society, 92, 104465.
10. Mihalakakou, G., Souliotis, M., Papadaki, M., Menounou, P., Dimopoulos, P., Kolokotsa, D., ... &Papaefthimiou, S. (2023). Green roofs as a nature-based solution for improving urban sustainability: Progress and perspectives. Renewable and Sustainable Energy Reviews, 180, 113306.
11. Sordello, R., Busson, S., Cornuau, J. H., Deverchère, P., Faure, B., Guetté, A., ... &Vauclair, S. (2022). A plea for a worldwide development of dark infrastructure for biodiversity–Practical examples and ways to go forward. Landscape and Urban Planning, 219, 104332.
12. Zielinska-Dabkowska, K. M., Szlachetko, K., &Bobkowska, K. (2021). An impact analysis of artificial light at night (ALAN) on bats. A case study of the historic monument and Natura 2000 Wisłoujście fortress in Gdansk, Poland. International Journal of Environmental Research and Public Health, 18(21), 11327.