# NavigatingDarkness:AProposalforDark Infrastructure to Reduce Light Pollution and Enhance Nature’s Pathways


## Abstract

*Light has become a formofspatialbarrier,muchlikearoadorwall, that disrupts wildlife movement. Therefore, the studyexplores how dark infrastructure can be used to supportnocturnalbiodiversitymovementacrossthefragmentedurbandistrict of Bonifacio Global City (BGC), Metro Manila,Philippines.Itframesdesigninterventionsasadualfunction:alight filter and a habitatcorridor.Thisisprimarilycarriedoutthroughabiotopemap,anecologicalmanagementmap,andanecological connectivity map of a chosen sub-watershed unitsurroundingBGC.Thefindingsrevealthatmuchofthesub-watershed unit requires creative and improvementstrategies, such as establishing vegetation buffers and replacingtraditional street lighting. Several nodes were subsequentlyplaced and connected to create dark movement routes fornocturnal wildlife and navigate the previously glaring urbandistrict.*



Keywords:lightpollution,nocturnalanimals,darkinfrastructure


## I. Introduction

Artificial light at night has become an overlooked environmental pollutant, altering natural ecosystems and disruptingbiologicalrhythms.Urbandistricts,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.

BonifacioGlobalCity(BGC),ahighlyilluminatedmixed-use urban district in Metro Manila, presents a compelling case of this challenge. While designed primarily for economic activity, its landscape produces intense nighttime luminance that interrupts ecological processes and isolates remainingvegetativepatches.This raises a critical question: how can landscapearchitecture strategically mediate between urban illumination and ecological continuity, particularly at night?

This study proposes a dark infrastructure as an ecologicalnetwork that filters artificial illumination while facilitatingnocturnal ecological movement. By approaching landscapeelements as both light buffers and habitat corridors, theresearch investigates how urban landscapes can bereconfigured to support ecological connectivity withoutcompromising essential urban functions. Through biotopemapping,ecologicalmanagementzoning,andconnectivity analysis of a sub-watershed area surroundingBGC,thestudyidentifieslandscape-basedinterventionsthat restore dark ecological routes across an intensely liturban fabric.


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## II. Review of Related Literature

Artificial light at night alters ecological processes and can function as a non-physical barrier to animal movement, especially for nocturnaltaxa.Severalempiricalandreview studies have established the scope of ecological light pollution, described how light intensity, spectrum, directionality, and timing affect organisms,andarguedfor landscape-scale mitigation methods. For example, Hale et al. (2015) argue that city lighting scenarios can create thresholdconditionsthatpreventbatsfromcrossinggaps 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).Thesesynthesesprovide the conceptualgroundingfortreatingdarknessasadesign variable that can be shaped by vegetation, lighting controls, and zoning to support nocturnal movement.

### A. Reviewofmanagementstrategies

**Create (establish new habitat and dark corridors).**

Landscape interventions that create new vegetativestructure and dark corridors are supported by studiesshowing that restoring or establishing vegetation at theurbanedgecanreduce the ecological impacts ofilluminationandprovidemovementhabitat.Haddocketal. (2019) demonstrated that artificial lighting at urbanforest edges reduces activity of insectivorous bats anddecreases the effective habitat available to light-sensitivespecies, which implies that establishing vegetated buffersthat screen and intercept light can expand usable habitatand re-open movement routes. Similarly, Barba et al. (2023)demonstrate that dense, continuous tree canopies withminimal gaps and sufficient height serve as movementcorridors, increasing both species diversity and activitywithinilluminatedurbancontexts.Additionalfindingsfrom Melbourne reveal that open green spaces embeddedwithin areas of higher tree density and lower road densitysupport greater bat presence, emphasizing the ecologicalvalueofcreatingstrategicallylocatedvegetatedbuffersthat filter light and reconnect habitat (Callas et al., 2024).Together, these studies show that creating new greencorridors, buffers, and patches with deliberate canopystructure and connectivity can both shield landscapes fromintrusive lighting and reestablish ecological movementroutes for light-sensitive species.

**Improve (retrofit and upgrade existing sites andlighting).**

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 mitigationrecommendfull cutoff fixtures, dimmingschedules,motionactivation,and spectralmanagement,suchasusinglowercorrelatedcolor temperatures to reduce shorter wavelength, blue-rich output that is particularly disruptive to many taxa (Longcore et al., 2023; Jägerbrand & Bouroussis, 2021). Empiricalworkalsoshowsthatconvertingbroad-area, constant illumination to adaptive systems reducescontinuous light exposure and can restore temporal darkwindows critical for nocturnal behaviors. In urbanconservation contexts, these retrofit strategies are oftencoupledwithhabitatenhancementmeasures,suchasthose highlighted in other management categories, so thatimproved lighting does not simply move the problem toadjacent 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 spatialconfigurationinfluencewhetheranimalswillcross open spaces, indicating that continuity of low-light corridors is necessary to maintain movement. Policy and guidancebriefsadvocateformulti-zonelightingstrategies thatdeliberatelycreatedarkcorridorsorreduced-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 habitatsandapplyingmoreconstrainedlightingprinciples within and around them, while case studies and reviewsof bats and other nocturnal taxa show that preserving undisturbed dark corridors or exclusion zones can maintain foraging and commuting routes that would otherwisebelosttoencroachingillumination (Zielińska-Dąbkowska et al., 2021; Haddock et al., 2019).

## B. Synthesis

The emerging literature indicates that restoring nocturnalecological connectivity in brightly illuminated urbandistricts requires a coordinated suite of landscape andlighting interventions rather than isolated measures.Studies consistently show that structurally complexvegetation,strategicallydeployedacrossfragmentedurban fabrics, can buffer artificial illumination whileexpandinghabitatandfacilitatingmovementforlight-sensitivespecies.Atthesametime,researchon 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 intentionaldesignresourcecapableofreconfiguringurban environments into more permeable, ecologically responsive networks.

## III. Methodology

The study utilized QGIS, a geographic information system, tocreatevariousmapsforanalysis.Thedatainsomemaps is imported to the software from geoportal PH and lightpollutionmap.info.

Thedatagatheringprocessbeganwithidentifyingasuitable sub-watershed unit encompassing BGC. Mappingprocedures were then conducted to determine the soilcharacteristics,slopeconditions,andlandcoverwithinthis unit. These datasets formed the basis for developing abiotope map, which was subsequently categorizedaccording to area, period of development, rarity, habitattype, and levels of light pollution. This was furthersupported by a value assessment matrix and a set ofassessment criteria. Collectively, these componentsinformed the preparation of the ecological managementmap and the ecological networking map.

In the development of a dark infrastructure in the final map,thisresearchadaptsthefour-stepprocessofSordello 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. Forinstance,stepfourisnotperformedbecauseitrequires 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.

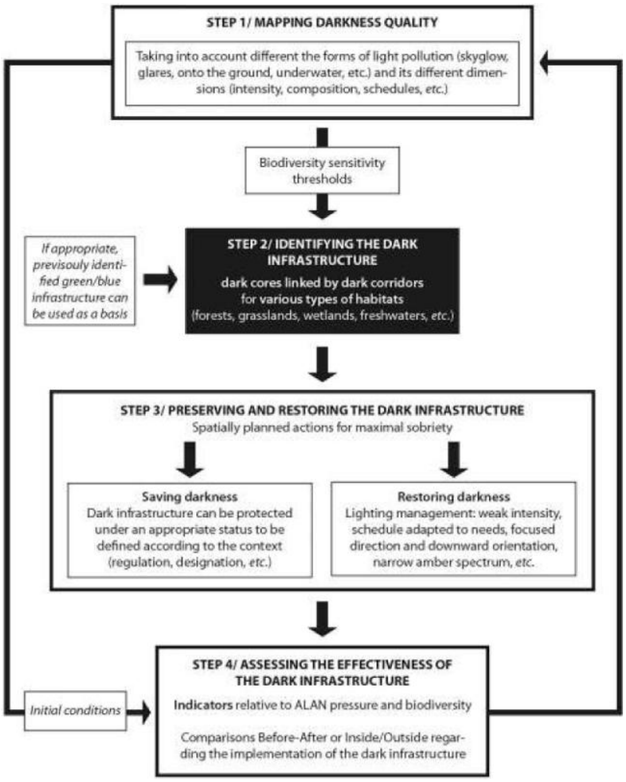


**Figure 1.** Four-step processtoidentify,preserve, and restore dark infrastructure.

*Source:Sordelloetal.(2022).*

# IV. Gathered Data

## A. WatershedMap

ThemapillustratesthestudyareaofBGCandthechosensub-watershedunit.

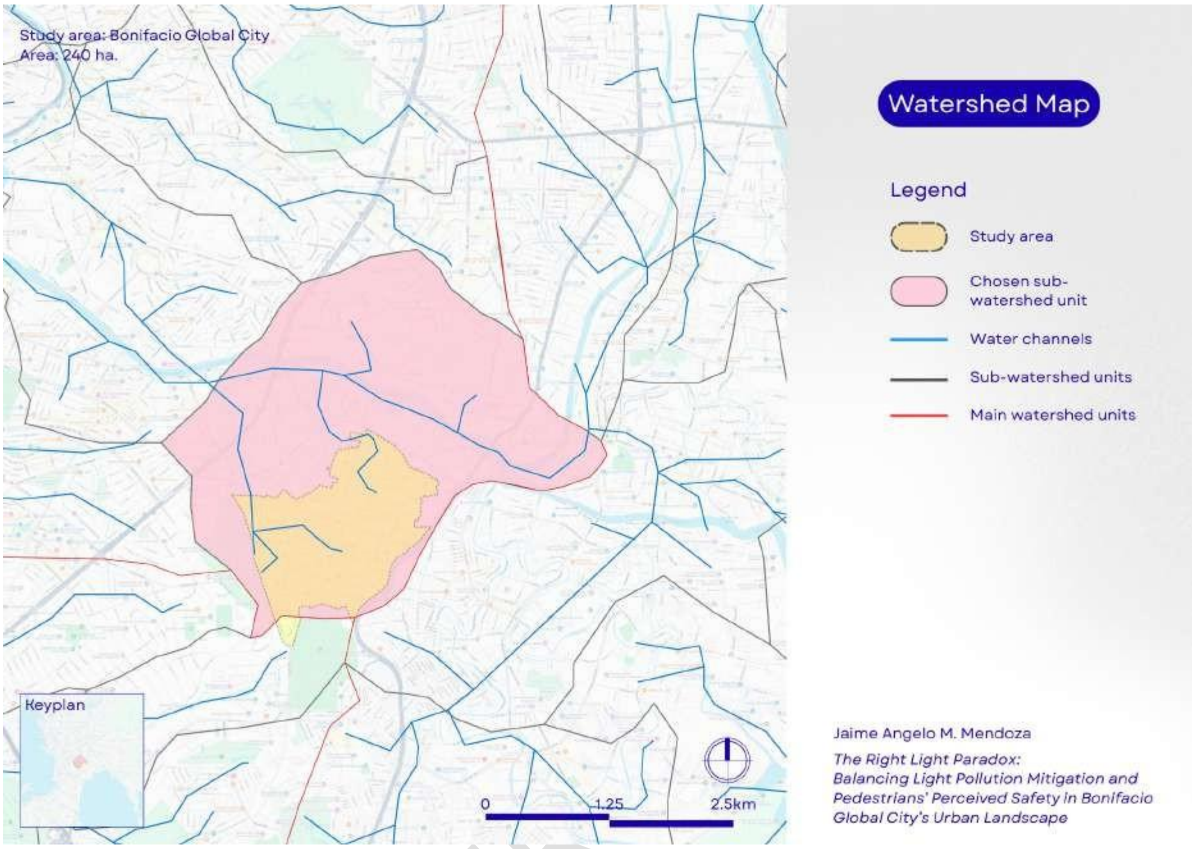


**Figure2.**WatershedMap.

*Source:Author's own.*

## B. BiotopeMap

Thebiotopemapisderivedbyintersectingthreemaps:soil,slope,andlandcover.Itreveals125uniquebiotopetypes.

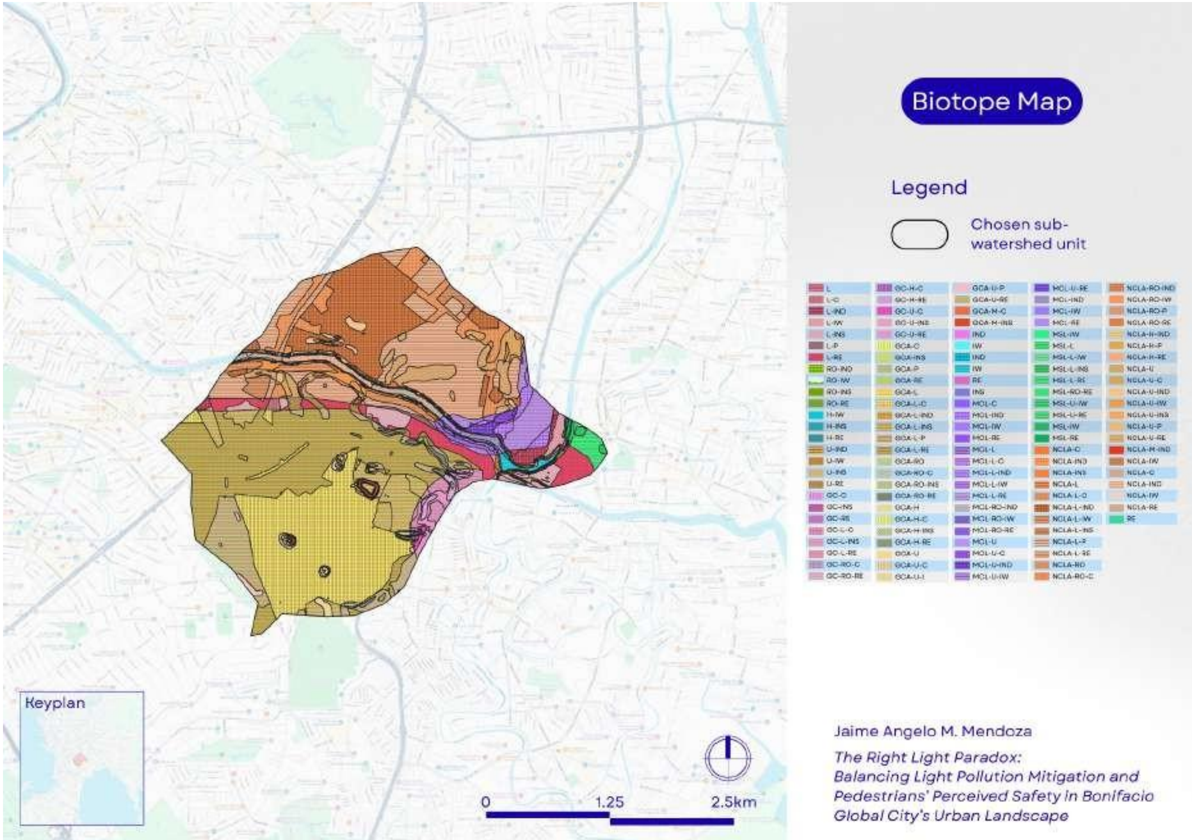


**Figure3.**BiotopeMap.

*Source:Author's own.*

## C. EcologicalManagementMap

Using the biotope map, it is further categorized into its area, period of development, rarity, habitat, and light pollution. 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 |

**Figure4.**Valueassessmentmatrixandassessmentcriteria.

*Source:Author's own.*

Eachbiotopeunitisevaluatedandassignedacorrespondingmanagementstrategy:create,improve,integrate,or preserve. The following map visualizes this.

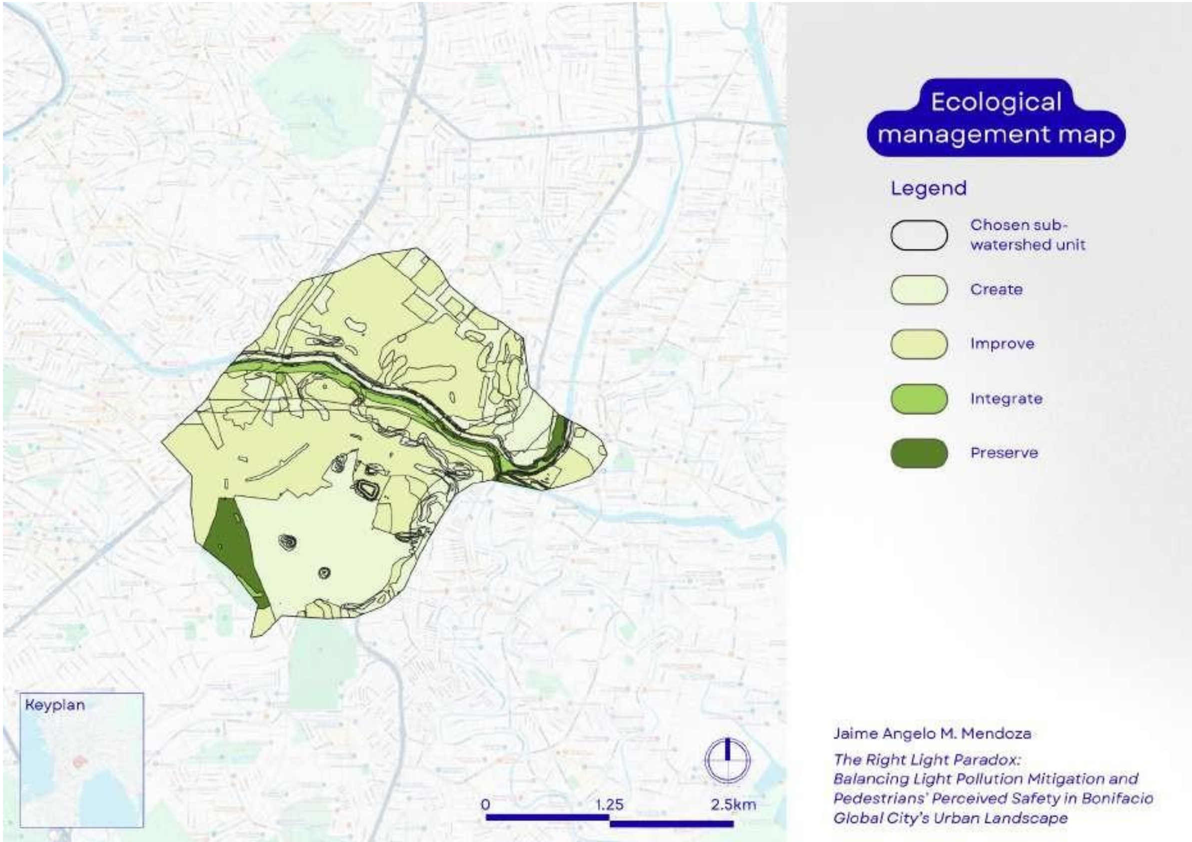


**Figure5.**EcologicalManagementMap.

*Source:Author's own.*

## V. Results and Analysis

### A. Managementstrategies

Thespecificmanagementstrategiesareproposedtoreducelightpollutionandenhancehabitatconnectivity.

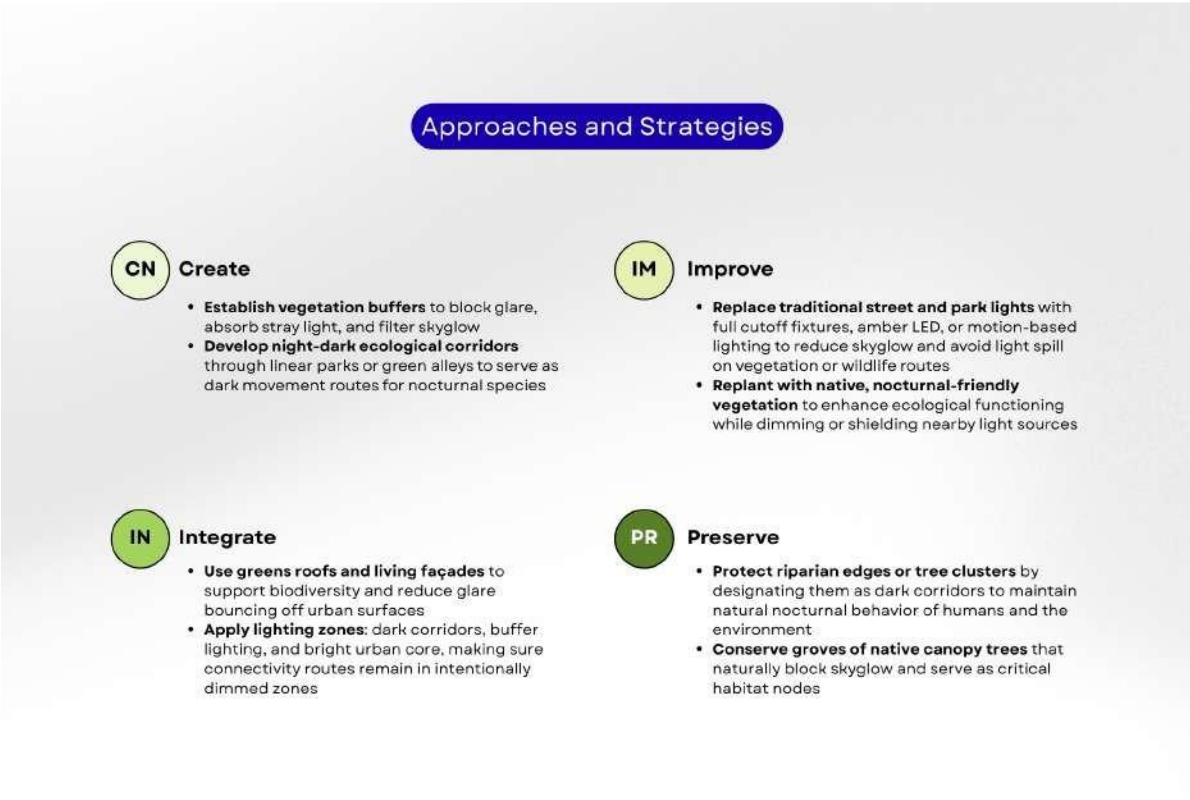


**Figure6.**Managementstrategies.

*Source:Author's own.*

## B. EcologicalNetworkingMap

Several nodes and corridors arelocated.Nodesaresmallpocketsofhigher-qualityhabitat,suchasparks,treeclusters,or vegetated setbacks, that provide food, shelter, or temporary refuge for species moving through the city. Corridors, meanwhile, are the linear pathways that connect these nodes, allowing animals to travel safely across otherwise inhospitable urban areas. These corridors can take the form of tree-lined streets, vegetated walkways, shaded edges, or darker micro-routes that reduce exposure to lighting and disturbance. Together, nodes serve as ecological “stations,” while corridors function as the “routes” between them, forming a network that enables wildlife tonavigatedenseurban environments despite fragmentation and light pollution. The nodes correspond to varying management strategies.

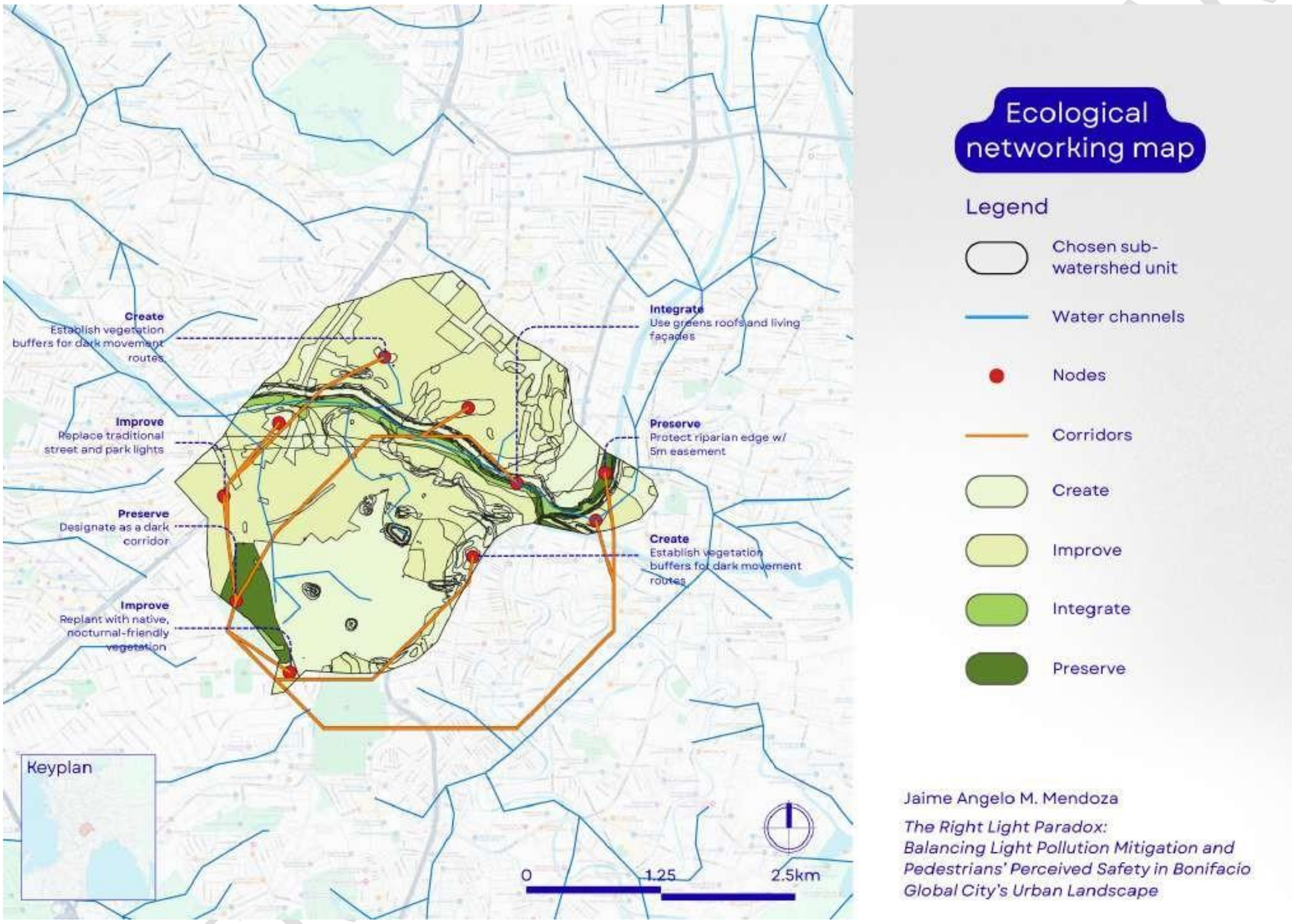


**Figure7.**EcologicalNetworkingMap.

*Source:Author’s own.*

## C. EcologicalNetworkingMapwithLightPollutionMap.

Thenodesareselectedbasedontheamountoflightpollutionintheirgivenarea.Hence,nodeswerepreferablylocatedin areas L2, L3, and L4. They are then connected to createadarkmovementroutefornocturnalwildlife.Thecorridorsare based on a least-cost path analysis that finds optimal pathways (i.e., the least light-polluted area) when connecting to different nodes. This is a similar approach done by Hu et al. (2021) in their study on ecological corridor construction.

For example, the corridor on the bottom right notably strays beyond the chosen sub-watershed unit. This is because it allows for a darker pathway, rather than directly connecting to the next node.

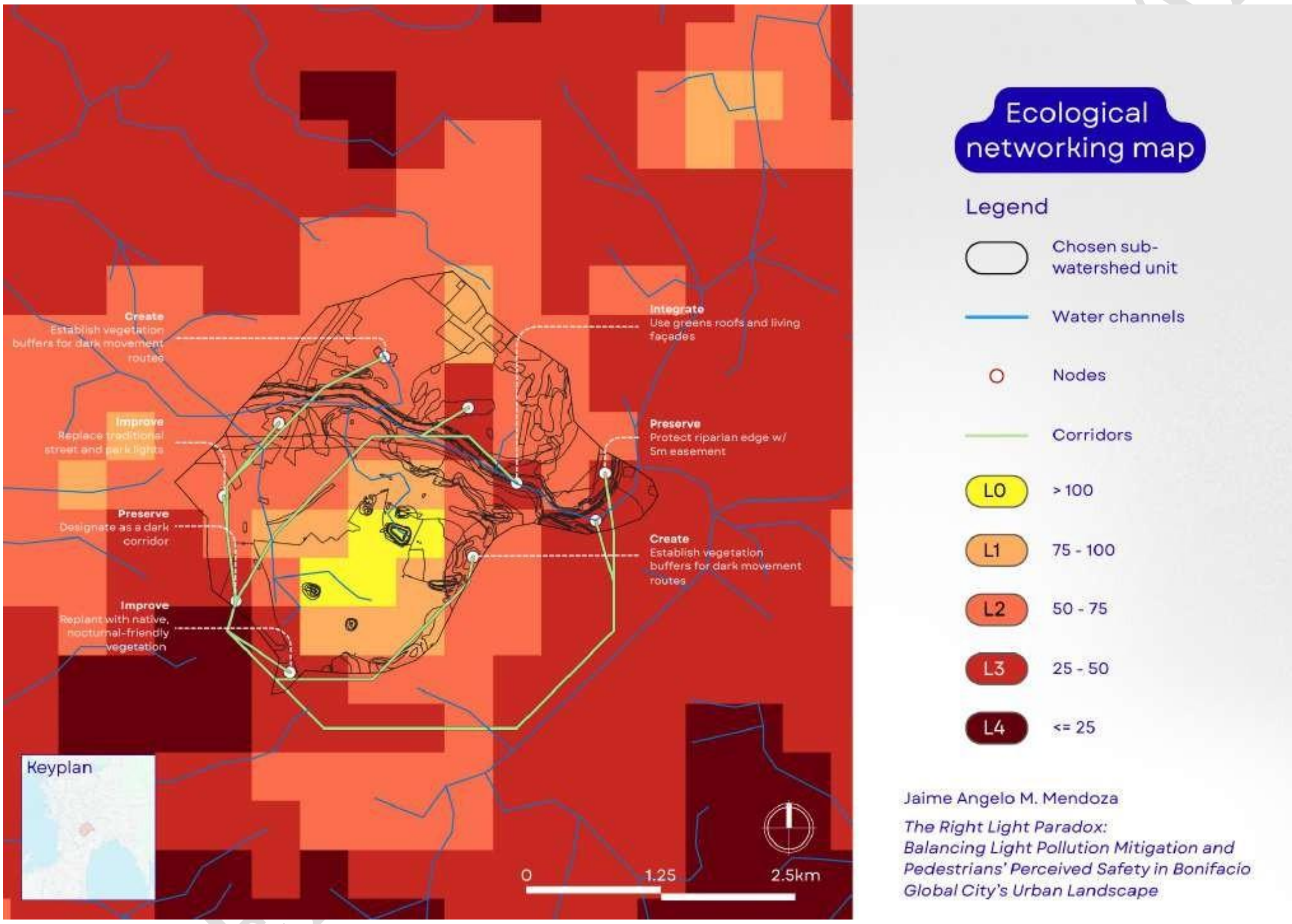


**Figure8.**EcologicalNetworkingMapwithlightpollutionmap.

*Source:Author's own.*

## VI. Conclusion

This study demonstrates that artificial illumination in BGCfunctionsnotonlyasanenvironmentalpollutantbutalsoas a spatial barrier that fragments ecological networks andobstructsnocturnalwildlifemovement.Throughaproposed dark infrastructure, the research highlights thepotential of landscape architecture to mediate betweenurban illumination and ecological continuity.

Through biotope mapping, ecological managementzoning, 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 fabricdemonstratehow dark ecological routes can be intentionally shaped to reconnectfragmentedhabitats,evenwithin high-luminance districts.

Ultimately, the findings affirm that mitigating light pollution and enhancing ecological connectivity are not competing objectivesbutcanbesynergisticallyaddressed through landscapearchitecturalinterventions.Bytreating landscapesasbothlightfiltersandhabitatcorridors,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 viewslight not only as infrastructure but also as amaterialforspatial control, ecological influence, and design agency.

Moving forward, the development of dark infrastructureshouldbefurtherstudiedjustasithasbeenwithitsblue-green infrastructure counterpart. According toSordello et al. (2022), most international conservationstrategies take little to no account of darkness. Hence, it ishoped that future research can likewise take more interestin this topic.

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