# Integrating Habitat-Quality and Entropy Coefficient Methods to Derive Habitat Resistance Surfaces for Simulation of Ecological Connectivity Network

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都市計画で緑地を整備する場合､現地の生物多様性を守るには計画段階で生態学的な接続性を重視し､野生生物の移動回廊を確保することが重要だ｡本稿ではケソン市を例に､都市計画が生態系に及ぼす影響をシミュレーションした｡

**Abstract**

Closely coupled with the issue of broadscale loss of natural habitats is the challenge of maintaining and conserving biodiversity in landscapes now dominated by human land use. In Quezon City, the LGU plans to create the Green Lung Network featuring a chain of developments linking La Mesa Nature Reserve, the largest green space in Metro Manila, to all the open spaces and parks in the city. However, it is focused solely on creating green corridors for human mobility. Hence, it is a challenge to connect La Mesa Nature Reserve to other green spaces of the city to create an ecological network which will disperse and enrich biodiversity all over the city.

To address this, the study aims to create an ecological connectivity network for Quezon City based on behaviour and preference of focal species as parameters and indicators for movement along corridors. This study considers not only the distance between habitat patches, but also the spatial, ecological, and other landscape factors to model the integrated structural and functional connectivity of the landscape. It involves simulating the sensitivity of different land covers to impact factors. The set of procedures used in this study illustrated how the concept of ecological networks may be integrated into the urban planning process.

**Keywords** Ecological Connectivity Network; Ecological Corridors; Focal Species; urban birds; corridor simulation

## Introduction

Even before the Covid-19 pandemic which forced people to limit outdoor activities and made people crave for green and blue infrastructures, the economic growth in urban areas has been making humans more dependent on ecosystem services and biodiversity. Improving human well-being might be a by-product of successful conservation in urban areas, but this effect can, in turn, catalyse people to be more supportive of other efforts at biodiversity conservation. Therefore, it is particularly important to maximize ecosystem service values by constructing networks that enhance the functionality of urban ecosystem services.

Planners are faced with urban landscapes often in need of policies directed to the conservation of biodiversity. Planned green spaces and those that act as buffers or fillers in urban developments are usually not designed as potential habitats for biodiversity, found dotted in many cities, and often cater only to the recreational needs of urban dwellers [1].

Ecological network studies provide a framework which offers a design that regards the combination of a system of nature reserves and their interconnections which make a fragmented natural system coherent to support more biological diversity than in its non-connected form [2]. It ensures biodiversity conservation by protecting core areas and connecting them through corridors that should enable species to move across unsuitable areas.

In the Philippines, Quezon City (QC) is one of the most developed cities, ranking first in economic dynamism and second in infrastructures [3]. As a result, the habitat patches in this city are significantly affected by urbanization. Among the developments is the MRT 7 line which already led to removal of 1,858 trees [4] and can possibly lead to loss of natural habitats and further landscape fragmentation which will go against the goal of the city government in creating a garden city. Moreover, La Mesa Nature Reserve which acts as mother node in the metapopulation zone of QC, an important breeding and roosting area for a variety of wildlife species including birds [5], and represents 36% of the green spaces in QC, is separated from other ecological cores by the MRT 7 line and wide highways traversing the city.

Along with the new transportation system, the city government made a Comprehensive Land Use Plan for 2030 which includes the Green Lung Network featuring a chain of developments linking all the open spaces and parks in the city [6]. However, it does not address the functional and structural connectivity of green spaces and is focused solely on creating green corridors for human mobility.

## Conceptual Framework

Assessing connectivity for development of an ecological network by using efficient models is essential to improve these networks under rapid urban expansion. With the Focal-Species Approach, this study employs two target species with different uses of landscape structure. This approach aims to optimize the continuity and conditions of green spaces within the study area so that opportunities for individual passage may be maximized for a wide range of species. Species that are present within the identified habitat patches may benefit from the establishment of connective landscape features between them if the composition of vegetation within such patches is sufficiently similar. As similar species may benefit to a greater extent from particular landscape attributes than others, the approach used here effectively aims to restore the condition of habitat and thus most likely to suit the individual requirements of the species present. [7]

Previous research undertaken by this author [8], identified the parameters for movement along green spaces using empirical habitat-use data on the preference of biological indicators/focal species in QC. The study was able to identify the focal nodes which represent the key habitat patches of interest in QC between which flows are modelled in circuit analysis for simulating an ecological connectivity network. The species used were Eurasian tree sparrow (*Passer montanus*) and Yellow-vented bulbul (*Pycnonotus goiavier*) which are the top 2 urban bird species in Metro Manila [9]. These species represent different functional guilds and habitat preference that help to link the structure and functional connectivity of green space [10]. Both are important seed dispersal animals in urban areas which makes them suitable model species to study the conservation priorities closely linked to ecological and human environments [11]. Therefore, this study integrates the resulting focal nodes to the creation of resistance surfaces for modelling the connectivity of green spaces for the two mentioned bird species found in QC.

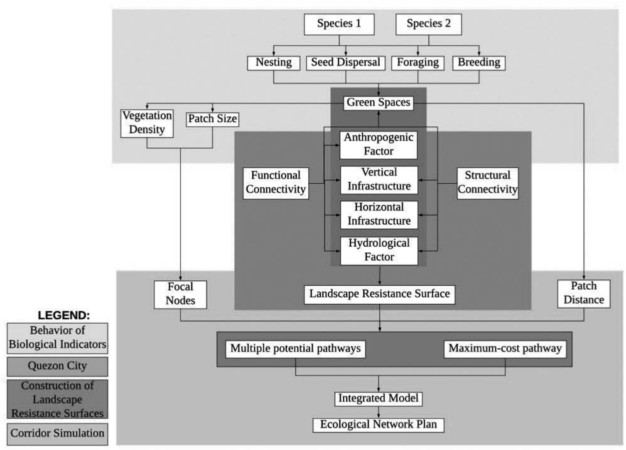



**Fig. 1: Conceptual Framework**

For a corridor design to become defensible and successful, the design framework must be able to address objections that may arise in the process specially when using focal-species approach [12]. Hence, the conceptual framework (Fig. 1) in this study addresses the common objections in the use of Ecological Network

Plan (ENP) in designing corridors for urban planning. The most important step when creating corridor simulation using graph theory is the appropriate parameterization of the model which means construction of resistance surfaces. It has a major impact on the simulation of corridors; hence, many studies construct resistance surfaces based on various methods.

Most studies have constructed landscape resistance surfaces based on expertise and overall ratings for certain land-use types, resulting to landscape resistance surfaces being heavily dependent on grading factors [13][14]. There are differences between the same land-use types owing to their different locations and surroundings. As a result, previous studies have weakened the differences in resistance of the same land-use type. In this research study, the author proposes a habitat quality-based method used by Gao et al., [17]. It involves simulating the sensitivity of different land-use types to impact factors. With this method, the functional connectivity of the habitat patches is measured. For the structural connectivity, creation of the resistance surface is based on the entropy coefficient method which utilizes landscape indexes as the ecological attributes for each land-use type in the weighted calculation.

To identify potential corridors for the focal species, this study combines circuit models and least-cost models by integrating structure and function of green space patches for providing reliable ecological connectivity network models in the cities. This approach (also called graph theory) allows for multiple least-cost pathways to be evaluated for their contribution to the configuration of the overall network.

The ecological network developed by the integrated models in this study simplifies and systematizes the complex landscape, helping to identify the significance of each green space and guiding urban planning for biodiversity conservation by identifying the relative high-quality habitats and choosing the best opportunities to maintain and restore connectivity.

# Methodology

The research strategy used in this study was modelling or simulation using different tools and techniques in Geographic Information Systems. A data-based framework was applied, minimizing the use of subjective assumptions to assess habitat connectivity. Creating an ENP starts with identification of focal nodes. The focal node maps for each species as well as the final focal node map for QC which were generated from the previous study made by the author [8] were used as the focal nodes for the circuit model and least-cost model analysis. Hence, in this study the focus is on the succeeding steps which are construction of habitat resistance surfaces and modelling of different connectivity maps using circuit model and least-cost model and integrating the two models to create the ENP.

Figure 2 shows the methodological framework which reflects the conceptual framework and GIS tools. In creating resistance maps, two methods were used: the Habitat-Quality Method (HQM) and the Entropy Coefficient Method (ECM), both methods were proposed by Gao et al [15]. HQM generates resistance map using functional metrics whereas ECM uses structural metrics. The landscape resistance and green space structure linked to the behaviour of species were used as parameters and indicators for movement along corridors.

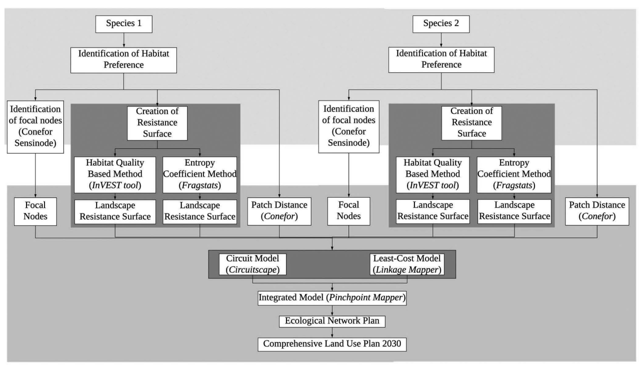



**Fig. 2: Methodological Framework**

Developing landscape connectivity models using circuit theory parameterised with green space structure characteristics such as size and density allows the modelling of multiple paths between nodes [16]. The use of circuit theory to depict spatial patterns of landscape resistance or conductance provides an easily interpretable method for calculating metric values and modelled linkages [17]. The least-cost path analysis represents the route of maximum efficiency between two locations as a function of the distance travelled and the costs traversed. It is a valuable method for conservation planning by analysing and designing habitat corridors as it allows quantitative comparisons of potential movement routes over large study area; incorporates simple or complex models of habitat effects on movement; and influences functional connectivity for species movement [18]. Corridor designs for multiple focal species were combined into a preliminary linkage design which became the final linkage design after it was modified to accommodate ecological processes, incorporate other pixels of conservation interest, buffer against edge effects, or achieve other objectives.

To provide an idea of how the connectivity models could be used to improve connectivity for future planning, the combined model was overlaid to Green Lung Network Plan of QC.

***1. Construction of habitat resistance surfaces:***

**a. Habitat-Quality Method (HQM)**

To simulate the sensitivity of different land-use types to impact factors, this study uses the HQM which involves analysing how the intensity of human activity influences habitat quality of QC's landscape. Pixel-scale habitat quality was used to characterize the optimal survival, reproduction, and energy flow conditions that an assessment unit provided to organisms. This was adopted from the habitat quality component of the biodiversity module InVEST Tool (Integrated Valuation of Ecosystem Service and Tradeoffs) which uses a framework delineating "supply, service, and value" to link production functions to the benefits provided to people [19]. Its models are "based on production functions that define how changes in an ecosystem's structure and function are likely to affect the flows and values of ecosystem services across a land- or a seascape" [20]. One of these models is the HQM which combines information on Land Use and Land Cover and threats to biodiversity to generate two key sets of information that are useful in making an initial assessment of conservation needs: the habitat quality index and habitat degradation index of a landscape. It characterizes the sensitivity of habitat types to various threats and allows users to estimate the relative impact of one threat over another so that threats that are more damaging to habitats of the focal species and to biodiversity persistence on the landscape can be represented as such. [19] The impact of threats on habitat in a grid cell is mediated by four factors: 1) relative impact of each threat, 2) distance between habitat and the threat source and the impact of the threat across space, 3) the level of legal / institutional/ social / physical protection from disturbance in each cell, and 4) relative sensitivity of each habitat type to each threat on the landscape. These factors are incorporated in the modelling process through the raster datasets and CSV files.

The HQM considers threats to be human-modified land cover types that cause habitat fragmentation, edge, and degradation in neighbouring habitat. They are threats that do not directly affect the focal species but the habitat quality of the green spaces which then affect the quality of possible nesting and breeding patches of the focal species. In this study, there are four types of identified factors that impact the habitats of the two bird species: horizontal infrastructure represented by map of roads and MRT7 line), vertical infrastructure (represented by building footprints/built-up area map), hydrological factor represented by waterbodies map), and anthropogenic factor (represented by human population density map). Below are reasons why these factors were chosen for constructing the resistance surface of QC:

- **Horizontal Infrastructure**

Linear disturbances such as roads and railways tend to be completely connected, relatively straight and subject to regular human disturbance; hence, they serve as barriers that subdivide populations of species into metapopulations [21]. Based on several studies [22][23][24][25], bird abundance and breeding success tends to decrease with increasing noise associated with road development disturbances and birds are more vulnerable to roadkill than mammals on divided highways with forested medians due to their willingness to cross narrow gaps. Birds alter their flight patterns near the high-speed railways, including showing some avoidance of it [26]. However, birds risk train collision because such avoidance is not complete. Moreover, road noise significantly affects the habitat preference of birds. Effect distances ranged from 20-1500 meters at 10,000 vehicles per day and increased to 70-2800 meters at 60,000 vehicles per day [24]. In the case of QC, year 2016 reported 272, 255 vehicles per day passing through Commonwealth Avenue, which is also the route of MRT7 line [27]. This means that buffer width of more 2,800 meters is needed in habitats along Commonwealth Avenue.

**• Vertical Infrastructure**

Aside from scarcity of food supply and place to breed, built-up areas pose a great threat to birds due to buildings. In the study by Loss et al. [28] involving the review and analysis of more than 92,000 records across 23 studies, it was found that between 365 and 988 million birds are likely killed in the United States each year as a result of collisions with buildings. Towering skyscrapers might seem like the most obvious culprits, yet Loss's team found that 56 percent of the mortality occurs at low-rises (4-11 stories tall); 44 percent at residences (1-3 stories tall), and less than one percent at high-rises (12 stories and up).

The number of trees and buildings are also the most significant predictors of bird abundances. Trees and buildings in Metro Manila affect the distribution and abundance of urban exploiting species *Passer montanus* and *Pycnonotus goiavier* with the former favouring the built spaces and the latter favouring trees [9].

**• Hydrological Factor**

Water bodies are considered physical barriers to movement of birds [29]. The focal species used in this study both have a maximum dispersal distance of only 1,000 meters; hence, it will be difficult for them to cross La Mesa Lake which is more than 1 kilometre in diameter. Aside from effect on dispersal distance, water bodies in urban areas most often are not of good quality, negatively affecting the vegetation in habitat patches. Based on the 2018 report from the Department of Environment and Natural Resources, only 85 percent of the total garbage volume from Metro Manila is being collected to be disposed at sanitary landfills and QC showed to be the highest waste producer in the metro generating 3,151,961 kg a day [30]. The uncollected waste ends up mostly in rivers, esteros, and other water bodies, thus, polluting major water bodies and clogging the drainage systems. The Tullahan River alone, which stretches from QC to Navotas City, has an average coliform level of 500 million most probable number (MPN), far from the safe level of 200 MPN [31]. Hence, urban water bodies not only negatively affect dispersal distance, but also quality of possible nesting and breeding patches.

**• Anthropogenic Factor**

Decreased habitat availability, reduced patch size, increased edge, increased non-native vegetation, decreased vegetative complexity, and increased nest predation were commonly associated with bird declines in response to human settlement [32]. Based on several studies [33][34] sheer population density is associated with lower numbers of bird species and individuals, so regardless of income or poverty, bird diversity is lowest where human populations are most dense.

**• Threats data CSV file**

Based on the habitat preference of the two bird species [8], a CSV (comma-separated value, .csv) table of all threats to be modelled was created. The table contains information on each threat's relative importance or weight and its impact across space. Each row in Table 1 is a degradation source. The maximum distance, measured in kilometres, is the maximum distance over which each threat affects habitat quality.

**Table 1. Attributes of Threats based on habitat preference of the focal species**

| Threat | *Passer montanus* | | | *Pycnonotus goiavier* | | |
|---|---|---|---|---|---|---|
| | **Maximum Distance** | **Weight** | **Decay** | **Maximum Distance** | **Weight** | **Decay** |
| Horizontal Infrastructure | 2 | 1 | linear | 2 | 1 | linear |
| Vertical Infrastructure | 5 | 0.7 | exponential | 5 | 0.8 | exponential |
| Hydrological Factors | 0.5 | 0.3 | linear | 0.5 | 0.1 | linear |
| Anthropological Factors | 6 | 0.8 | linear | 6 | 0.8 | linear |

The impact of each degradation source decline to zero at this maximum distance. In general, the impact of a threat on habitat decreases as distance from the degradation source increases, so that grid cells that are more proximate to threats will experience higher impacts. Weight is the impact of each threat on habitat quality, relative to other threats. Weights range from 1 at the highest impact, to 0 at the lowest. Since horizontal infrastructure has a threat weight of 1 and the threat weight of vertical infrastructure is set equal to 0.7 then the horizontal infrastructure causes 30 percent higher disturbance, all else equal, to all habitat types. The threats and weights were specific to the modelled focal species. The type of decay over space for the threat can have the value of either “linear” or “exponential”.

**• Accessibility to Threats shapefile**

This data presents the degree to which the land is legally protected. The HQM of InVEST tool assumes that the legal protection of land is effective and that all threats to a landscape are additive. Is the grid cell in the map located in a formal protected area? Or is it inaccessible to people due to high elevations? Or is the grid cell open to harvest and other forms of disturbance? The Habitat Quality Model assumes that the more legal / institutional / social / physical protection from degradation a cell has, the less it will be affected by nearby threats, no matter the type of threat [19]. The polygon shapefile containing data on the relative protection that legal / institutional / social / physical barriers provide against threats was created in ArcGIS Desktop 10.3. Polygons with minimum accessibility (e.g., strict nature reserves, well protected private lands) are assigned a number less than 1, while polygons with maximum accessibility (e.g., extractive reserves) are assigned a value 0. Any cells not covered by a polygon was assumed to be fully accessible and assigned values of 1. Table 2 shows the attribute table of the shapefile.

**Table 2: Accessibility Score of the areas in Quezon City**

| ID | Location | Accessibility Score |
|---|---|---|
| 1 | La Mesa Nature Reserve | 0.1 |
| 2 | Private Property | 0.1 |
| 3 | Arboretum Forest | 0.2 |
| 4 | Balara Filters Park | 0.3 |
| 5 | Capitol Hills Golf & Country Club | 0.4 |
| 6 | Bagbag Resevoir | 0.4 |
| 7 | Camp Aguinaldo Golf Course | 0.4 |
| 8 | Quezon Institute | 0.5 |
| 9 | ADMU, Miriam College, Pansol Area | 0.6 |
| 10 | Veterans Memorial Medical Center | 0.6 |
| 11 | UP Diliman | 0.7 |
| 12 | Ninoy Aquino Parks and Wildlife Center | 0.7 |

**• Sensitivity of Land Cover Types to Each Threat CSV file**

The CSV file containing the values of relative sensitivity of each habitat type to each threat on the landscape is the final factor used when generating the total degradation in a cell with habitat. The HQM assumes that the more sensitive a habitat type is to a threat, the more degraded the habitat type will be by that threat [19]. Each land cover type (Fig. 3) was assigned a habitat score from 0 to 1 (where 1 indicates the highest habitat suitability and 0 as the non-habitat area) based on habitat preference of the two bird species (Table 3). A ranking of less than 1 indicates habitat where a species or functional group may have lower survivability. Applying this second approach greatly expands the definition of habitat from the simple and often artificial binary approach (e.g., “natural” versus “unnatural”) to include a broad spectrum of both managed and unmanaged land cover types.

Since the continuum of habitat suitability is relevant, weights with a roster of land cover types on a landscape was applied in reference to habitat preference of the focal species. Since they prefer highly vegetated areas above all other habitat types the forest covers were given the score of 1. However, since they also make use grasslands and lawns if highly vegetated areas are not available, these land covers were given scores of 0.4 and 0.2 relatively based on vegetation density. The areas which were not vegetated were considered non-habitats and thus assigned the score of 0. Table 3 shows the relative sensitivity value of each habitat type to each threat. Values range from 0 to 1, where 1 represents high sensitivity to a threat and 0 represents no sensitivity. The raster files, shapefile, and CSV files were then loaded to the HQM of INVEST tool to compute the Habitat Quality index values with a raster map as final product. The Habitat Quality map produced by InVEST is then loaded to ArcGIS Desktop 10.3 to construct the landscape resistance surfaces. The quality values are converted to resistance values. Units of better habitat quality have smaller landscape resistance, and vice versa.

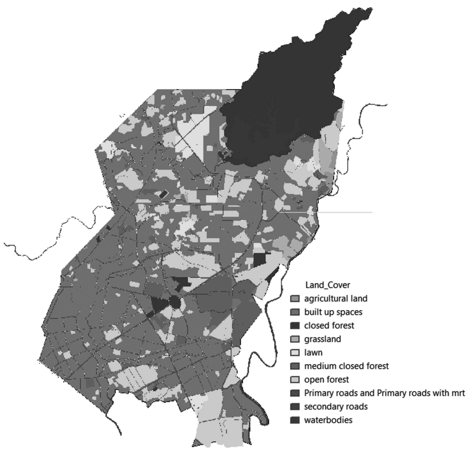



**Fig. 3: Land Cover of Quezon City**

**Table 3: Habitat Score of Land Cover and Sensitivity of Habitats to Each Threat based on habitat preference of the focal species**

| Land Cover | Habitat Score | | Sensitivity of Habitats to Each Threat | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Horizontal Infrastructure | | Vertical Infrastructure | | Hydrological factor | | Anthropogenic Factor | |
| | PM | PG | PM | PG | PM | PG | PM | PG | PM | PG |
| Closed forest | 1 | 1 | 1 | 1 | 0.9 | 0.9 | 0 | 0 | 1 | 1 |
| Medium closed forest | 1 | 1 | 0.9 | 0.9 | 0.9 | 0.9 | 0 | 0 | 0.9 | 0.9 |
| Open forest | 1 | 1 | 0.8 | 0.8 | 0.8 | 0.8 | 0 | 0 | 0.8 | 0.8 |
| Agricultural land | 1 | 1 | 0.2 | 0.2 | 0.3 | 0.3 | 0 | 0 | 0.7 | 0.7 |
| Grassland | 0.4 | 0.5 | 0.4 | 0.4 | 0.6 | 0.6 | 0 | 0 | 0.4 | 0.4 |
| Lawn | 0.2 | 0.5 | 0.3 | 0.3 | 0.5 | 0.5 | 0 | 0 | 0.4 | 0.4 |
| Waterbodies | 0 | 0 | 0.7 | 0.7 | 0.8 | 0.8 | 0 | 0 | 0.8 | 0.8 |
| Secondary roads | 0 | 0 | | | | | | | | |
| Primary roads and roads with MRT 7 | 0 | 0 | | | | | | | | |
| Built up spaces | 0 | 0 | | | | | | | | |

**b. Entropy Coefficient Method (ECM)**

ECM, as utilized by Gao et al [15] in their study, is an objective weighting method in which weight is determined by entropy. Entropy is the amount of additional information needed to specify the exact physical state of a system which in this study, is the spatial structure of QC. The greater the entropy, the more information it provides. It involves three steps: 1) normalizing the initial information matrix, 2) calculating entropy weight, and 3) calculating resistance. In this study, the landscape indexes were used as the ecological attributes for each land-use type in the weighted calculation.

To obtain the initial information matrix of landscape index values, Fragstats 4.3 tool was used, a spatial pattern analysis program for quantifying the structure/spatial heterogeneity (i.e., composition and configuration) of landscapes as represented in either a categorical map (i.e., landscape mosaic) or continuous surface (i.e., landscape gradient) [35]. Fragstats computes several statistics for each patch and class in the landscape and for the landscape as a whole. For the purpose of this study, the class level metrics was used. It measures the aggregate properties of the patches belonging to a single class or patch type. To quantify the configuration of patches at the class level is to summarize the aggregate distribution of the patch metrics for all patches of the corresponding patch type. Since the class represents an aggregation of patches of the same type, the class is characterized by summarizing the patch metrics for the patches that comprise each class [36]. The landscape indexes measured in this study are the following: Largest Patch Index, Patch Area, Shape Index, Fractal Dimension Index, Interspersion- Juxtaposition Index, and Connectance Index.

The raster file of QC's land cover was loaded to Fragstats 4.2 tool to produce an ASC text file containing the class-level values of the landscape indexes. This creates the initial information matrix to which the formulas proposed by Gao et al [15] are applied. In ArcGIS Desktop 10.3, the resistance values were used to reclassify the values of the Land Cover raster map to generate a resistance map based on spatial structure. The ECM was applied to the resistance values from HQM and resistance values from Entropy Coefficient calculation of spatial structure. The output values were then considered the overall resistance values which incorporated both functional and structural metrics. In ArcGIS Desktop 10.3, the overall resistance values were used to reclassify the values of the Land Cover raster map to generate the overall resistance map.

***2. Modelling of Corridor Map***

Least-Cost Model has been proven by different studies to be an effective way to calculate distances and to identify the most optimal routes between source sites [7][36]. However, it does not consider all possible routes that could contribute to connectivity, and it provides connectivity assessments that are only related to a single, most cost-efficient route identified in a given landscape [38]. In simulating the corridors, the use of Circuit Theoretic Model to overcome the limitation of the Least Cost Model is proven effective by several studies [7][16][37]. The circuit model was also able to spot critical connections that contribute the most to network connectivity and to identify corridors with optimal connectivity [7]. Hence, in the corridor simulation of QC, the circuit model is integrated to the least-cost model. To achieve this, Circuitscape and Linkage Mapper Toolkits are utilized to generate corridors based on least-cost model and circuit model. Both tools are installed and ran inside ArcGIS Desktop, although Circuitscape also has its standalone version.

In Circuitscape tool, landscapes are represented as conductive surfaces, with low resistances assigned to landscape feature types that are most permeable to movement or best promote gene flow, and high resistances assigned to movement barriers. Effective resistances, current flow, and voltages calculated across the landscapes can then be related to ecological processes, such as individual movement and gene flow [38]. Linkage Mapper automatically ran this when Pinchpoint Mapper tool is used.

Linkage Mapper, a suite of several ArcGIS tools, defines corridors through the landscape that minimize the cumulative resistance between pairs of nodes. In this study, three Linkage Mapper tools are used: Linkage Pathways, Pinchpoint Mapper, and Centrality Mapper. The Linkage Pathways tool uses the vector map of core habitat areas (shapefile of focal nodes) and raster maps of resistance to movement to identify and map the least-cost linkages between focal nodes. Each cell in a resistance map is attributed with a value reflecting the energetic cost, difficulty, or mortality risk of moving across that cell. In this study, the resistance values are determined by cell characteristics of land cover combined with species-specific landscape resistance models. The Linkage Pathways tool identifies adjacent focal nodes and calculate cost-weighted distances and least-cost paths between the focal nodes. It then creates maps of least-cost corridors between them and mosaics the individual corridors to create a single composite corridor map. The result shows the relative value of each grid cell in providing connectivity between core areas, allowing users to identify which routes encounter more or fewer features that facilitate or impede movement between core areas [38].

Once corridors have been mapped using Linkage Pathways, Pinchpoint Mapper utilizes circuit theory to run Circuitscape within the resulting corridors. This produces current maps that identify and map pinch points (i.e., constrictions, a.k.a. bottlenecks or choke points) in least-cost corridors. This approach hybridizes least-cost corridor and circuit theory approaches, showing both the most efficient movement pathways and critical pinch points within them. These pinchpoints could be prioritized over areas that contribute little to connectivity. [39]

Centrality Mapper analyses the resulting linkage networks, calculating current flow centrality across the networks. Current flow centrality is a measure of how important a link or node is for keeping the overall network connected [39]. Centrality analysis simultaneously considers the relations between all areas on a landscape providing a means to quantitatively incorporate connectivity within the planning process by ranking the contribution of those areas to facilitating ecological flows [40]. It utilizes Circuitscape to implement this circuit theory approach. It treats each core as a “node”, each linkage as a single resistor, and assigns a resistance equal to the cost-weighted distance of the corresponding least-cost corridor [41]. It then iterates through all core area pairs, injecting 1 amp of current into one core area and setting the other to ground. It then adds up current flow for each core and linkage to generate a map of cumulative current flow, indicating the importance of each linkage in maintaining connectivity across the entire network of cores, and can be considered as a measure of linkage and core centrality.

## Results

### *a. Effects of Landscape Resistance Surfaces*

Each cell in a resistance map is attributed with a value reflecting the energetic cost, difficulty, or mortality risk of moving across that cell. In HQM, two types of raster maps (Fig. 4 & 5) were created in analysing the current state of the landscape.

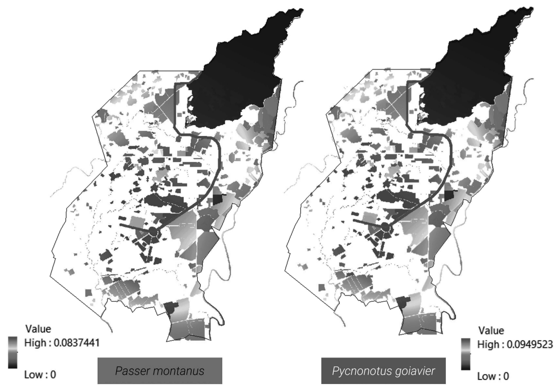



**Fig. 4: Relative level of habitat degradation on the current landscape.**

A high score in a grid cell of the raster map (Fig. 4) means habitat degradation in the cell is high relative to other cells. Grid cells with non-habitat land cover get a degradation score of 0; hence only the degradation level of green spaces is shown. The two maps show almost the same degradation values for both focal species. La Mesa Nature Reserve appears to have the lowest degradation value while the areas in the centre and south-eastern areas have the highest degradation values. This can be because these are the areas where building footprint is highly concentrated and where major roads pass through.

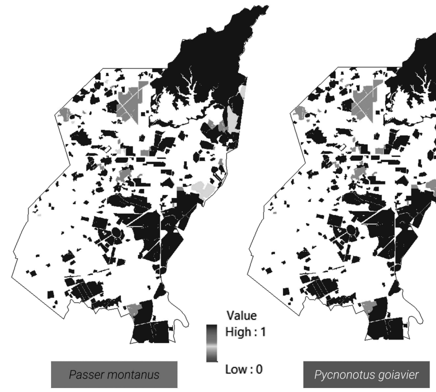
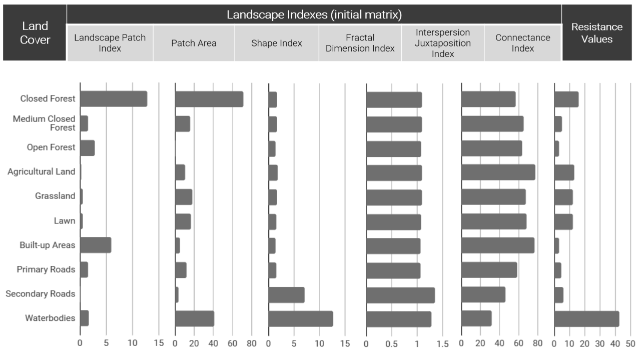



**Fig. 5: Relative level of habitat quality on the current landscape**

In Figure 5, as a grid cell's degradation score increases its habitat quality decreases. Higher numbers indicate better habitat quality vis-a-vis the distribution of habitat quality across the rest of the landscape. Areas on the landscape that are not habitat get a quality score of 0. This quality score is unitless and does not refer to any particular biodiversity measure. Hence, values are applied only on the green spaces. It is noticeable that the low-quality areas (orange, yellow, and yellow green) are lawns and grasslands which have low habitat score.


**Fig. 6: Resistance Map based on Habitat Quality Method (The higher the values, the higher is the energetic cost, difficulty, or mortality risk of moving across that area.) Good habitat quality promotes the dispersal of animals, and thus corresponds to low resistance [15]. So, when the quality maps were converted to resistance map using ArcGIS Desktop 10.3, the built-up areas had the highest resistance values.**

**Table 4: Landscape indexes of different land-use types (first six columns from the left) and landscape resistance estimates (last column) used in the entropy coefficient method (the axis at the bottom of the figure is the value corresponding to the indexes shown at the top).**




In the ECM which started from generating the landscape index values of the land cover of QC (see Table 4), the closed forest had the highest resistance value followed by waterbodies and agricultural land (see Figure 7). These habitat patches in QC are isolated due to properties of the edges themselves, the distance between patches, and properties of the intervening matrix, resulting to fewer individual movements among habitat patches.

Compared to the result of the HQM, the ECM put higher resistance values to habitats than on built-up areas and roads. In this method, connectivity was assessed by the extent to which movement is facilitated or impeded through different habitat types across the landscape. The attributes of habitats in QC facilitate movement through certain elements of the landscape and impeding it in others. The attribute values of the habitats in terms of functional connectivity facilitates movement while attribute values in terms of structural connectivity impedes movement.

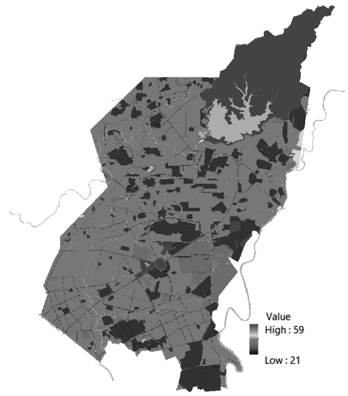



**Fig. 7: Resistance Map based on Entropy Coefficient Method (The higher the values, the higher is the energetic cost, difficulty, or mortality risk of moving across that area.)**

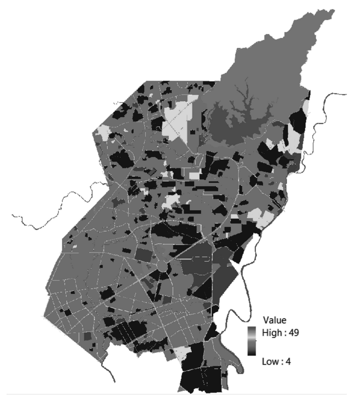



**Fig. 8: Overall Resistance Map for the two focal species (The higher the values, the higher is the energetic cost, difficulty, or mortality risk of moving across that area.)**

When the resistance surfaces from HQM and ECM were combined (see Figure 8) the waterbodies had the highest resistance values followed by built-up areas. Due to combination of resistance based on functional and structural connectivity the resulting resistance values referred not just to degree of barrier to flight movement but also on the energetic cost, difficulty, or mortality risk of moving across that area.

***b. Connectivity***

Figure 9 shows the cost-weighted distance (cwd) of the grid cells in the map to the nearest focal node. If a pathway from one node to another must pass through the allocation zone of a third, then the two nodes are considered nonadjacent. The nodes 4 and 8 below are not adjacent because it is impossible to move from one to the other without at least passing through the allocation zones of nodes of 2 or 9. The same is the case for nodes 13 and 10, which are blocked by allocation zones of nodes 11 and 12. This simply shows that even if there is no apparent physical barrier, connectivity of two nodes is blocked because of the attribute values of the resistance surface.

Based on the node adjacency and distances between nodes, Linkage Pathways tool created a "stick map" connecting focal node pairs that are candidates for corridor mapping. This map shows potential links between adjacent focal nodes. The links correspond to Euclidean (straight-line) distances between polygon edges. Using the focal nodes, resistance surface, and stick map, Linkage Pathways tool performed cwd calculations from each focal node area.

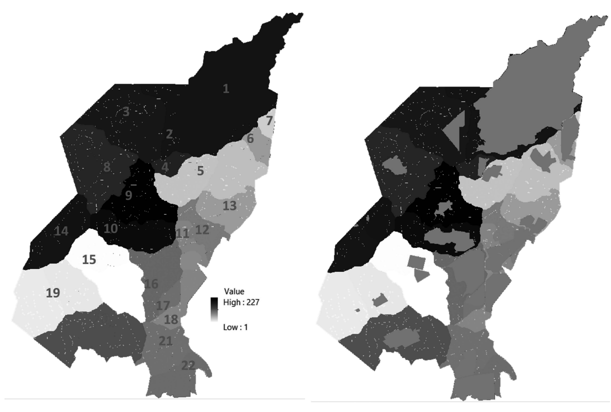



**Fig. 9: Adjacency of Focal nodes (Cost-weighted distance allocation zones).**

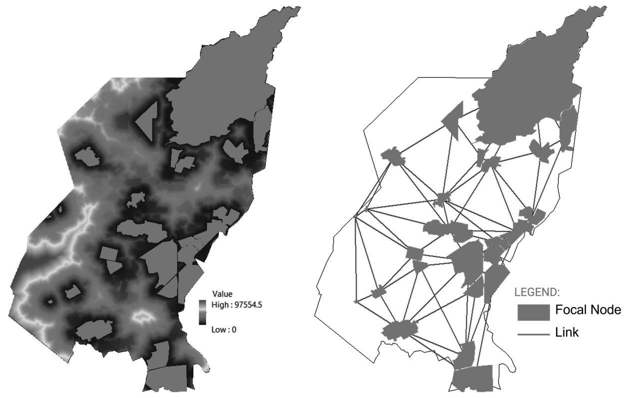



**Fig. 10: Left: As each cost-weighted distance surface is created, the minimum cost-weighted distances between source and target focal node pairs were also extracted. It shows the total movement resistance accumulated as animals move away from specific focal nodes. Right: The resulting cost-weighted distance raster and a direction raster for each node created the least-cost paths (the route along which the least resistance is accumulated) from node to node (right).**

ArcGIS Mosaic function created a composite linkage map in which each cell represents the minimum value of all individual normalized corridor layers. Figure 11 (left) shows these normalized and mosaicked least cost corridors. Blue grid cells are closer to corridor centres, with red cells showing routes that accumulate up to 97.5 kilometres cwd more than the optimal (least-cost) route. The blue areas, when clipped from the map resulted to the delineated corridors forming the Ecological Network Plan (Fig. 11 right).

By using Circuit theory to complement least-cost analyses important areas for connectivity conservation are identified. Pinchpoint Mapper tool hybridizes the outputs of least-cost corridor and circuit theory approaches to get the best of both approaches, showing both the most efficient movement pathways and critical pinch points within them.

Aside from allotting higher priority to pinch points, nodes and corridors with high centrality values should also be given higher attention for conservation. Centrality Mapper tool was able to delineate contribution of each node and corridor to facilitating ecological flows across the ecological network. Figure 14 shows the current flow centrality of nodes. Those in blue are considered the hub or the most important nodes for keeping the overall network connected. It is interesting to note that La Mesa Reserve came in as second priority. When it comes to importance of the corridors, links between the priority nodes also got the highest centrality values. However, one priority corridor linking UP Diliman to residential area of New Era crosses Commonwealth Ave and the MRT line which have high resistance surfaces. This goes to show that linking the two nodes is important to the overall connectivity of the network and a corridor between them should be given the utmost importance.

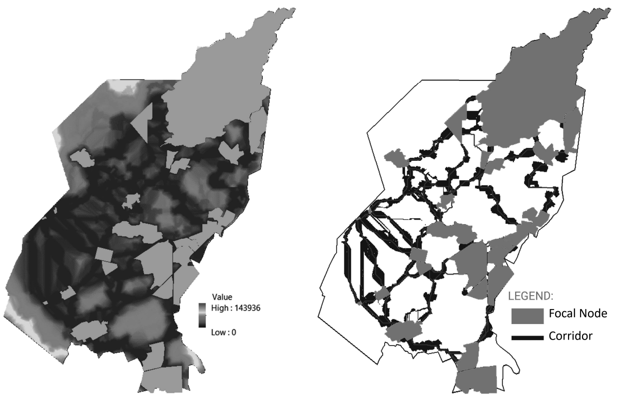



**Fig. 11: Least Cost Corridors (left) and Ecological Network Plan (right)**

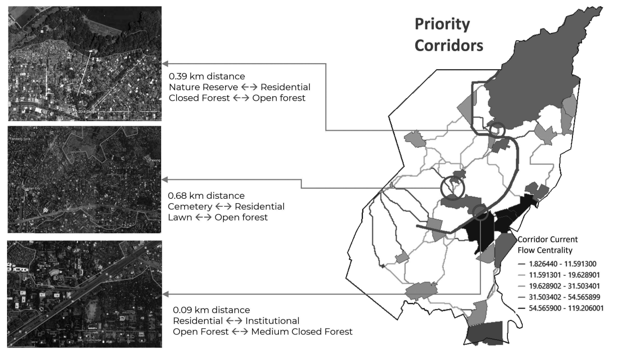



**Fig. 13: Centrality Values of the Corridors. The higher the value, the more important it is for keeping the network connected. (Red line is the MRT 7 line)**

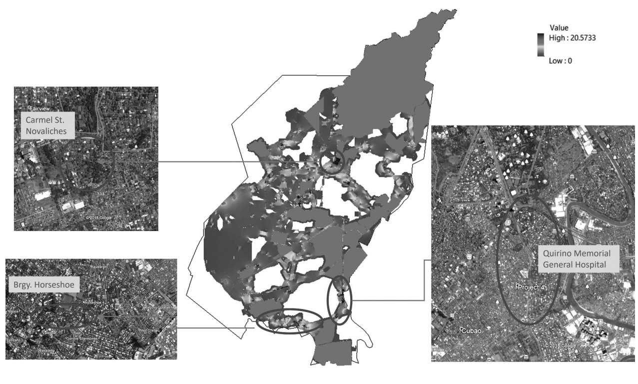



**Fig. 12: The blue and green pinch points represent areas where movement would be funnelled and thus particularly important to keeping intact. Most of these pinch points are residential and institutional areas (schools, hospitals, areas around barangay halls) with open to medium closed forests and private lands with closed forests. Even a small loss of area in these pinch points would disproportionately compromise connectivity. These areas could be prioritized over areas that contribute lesser to connectivity, such as the orange areas.**

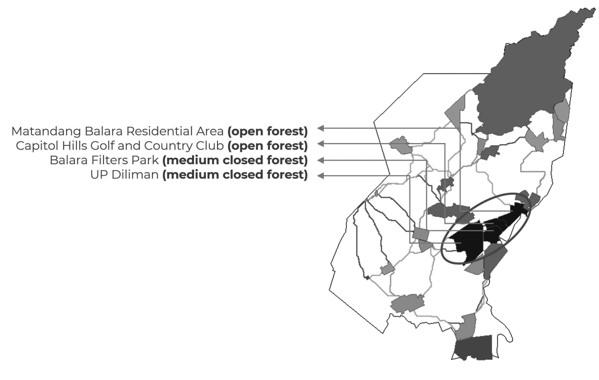



**Fig 14: Centrality Values of the Focal Nodes (The higher the value, the more important it is for keeping the network connected.)**

### c. *Ecological Network Plan vs Green Lung Network Plan*

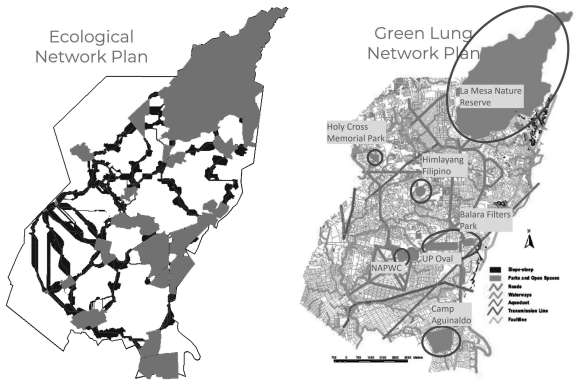



**Fig. 15: Green Spaces in the Green Lung Network (CLUP, 2030) (right) that matched the nodes in the Ecological Network Plan (left)**

Seven out of 10 green spaces in the Green Lung Network Plan matched the focal nodes in the Ecological Network Plan (Fig. 15). These green spaces comprise 58 percent of the total area of the focal nodes; however, 89 percent of these seven green spaces is just the La Mesa Nature Reserve. The 11 percent are composed of Holy Cross Memorial Park, Himlayang Filipino, Balara Filters Park, UP Oval, Ninoy Aquino Park and Wildlife Center, and Camp Aguinaldo. The three green spaces in the Green Lung Network Plan which were not included in the Ecological Network Plan are Quezon Memorial Circle, Arboretum Forest, and Ateneo de Manila University. These areas got high ICC values but not high enough to reach the value of 1 to make them focal nodes in the connectivity of QC's landscape for the use of the focal species. When it comes to corridor match, the Green Lung Network matches only seven percent of the routes of corridors in the ENP (Figure 16).

According to the CLUP 2030 [6] of QC, the Green Lung Network Plan, will link the La Mesa Nature Reserve to Quezon Memorial Circle (QMC) at the heart of the city by the green-lined Commonwealth Avenue, aqueducts, and rivers. In the ENP, QMC is not included in the focal nodes; however, its adjacent green spaces, NAPWC and Veterans Memorial Medical Center, were included in the focal nodes. Hence, the ENP is still able to achieve the goal of connecting La Mesa Nature Reserve to the centre of QC.

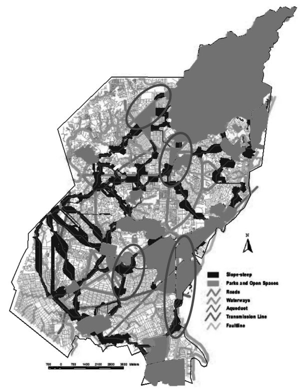


**Fig. 16: Greenways of the Green Lung Network that match the corridors in the Ecological Network Plan**

## Conclusion

In restoring previously altered ecosystems or protecting existing fragments of natural systems, landscape planners must recognize that the most effective way to re-establish or maintain the viability of these systems is to ensure they exist as a part of a larger functioning system. The development and articulation of a planning method based on ecological concepts, in particular the concept of ecological networks, can be integrated into the urban planning process. This study provided a framework of integrated models to test this proposition.

The impacts of Quezon City's land cover were considered within the larger, ecological context of landscape. To optimise corridor effectiveness for the focal species, this study integrated circuit and least-cost modelling which were parameterised with green space structures This study emphasizes the importance of considering the behaviour and preferences of existing species in the landscape when developing priority corridors of ecological connectivity networks.

Conserving the existing green spaces of QC and creating greenways to link them should not be just based on aesthetic reasons that affect only the populace. Using the Focal-Species Approach can help us ensure that we are managing the linkage as a semblance of a fully functioning ecosystem, rather than a narrow gauntlet that lets focal species pass between areas that threatens mortality rate. In such a rapidly evolving, heterogeneous, and highly fragmented landscapes, the identification of corridors which should be prioritized is important to better design, preserve, and improve ecological networks. Certain critical links or patches are required in order to support a viable existing patch so that isolation effect does not cause deterioration over time. In the resulting ENP, aside from it does not connect only the ecological cores of QC but also other tiny patches of green spaces, some corridors crossed the route of MRT 7 line instead of avoiding it. Hence, landscape planners of QC will have a more challenging task of designing the greenways to incorporate a design that will cater to an ecological corridor crossing the wide Commonwealth Avenue with MRT 7 line. For now, the MRT 7 line may not yet have a major impact on the fragmentation of QC, but if the LGU is not able to create corridors across it, the line may create a major divide in the city, causing greater loss of interior habitats along Commonwealth Avenue and worsening habitat fragmentation.

The ENP created in this study can be used to preserve or restore the ecological integrity of critical natural systems while allowing for compatible human activities within the network and continued productive (economic) use of adjacent lands. Some modification to adjacent land would enhance the viability of the network. Understanding the consequences of habitat change and developing effective strategies to maintain biodiversity in developed and disturbed landscapes are major challenges to both scientists and landscape planners. To be effective, it must integrate scientific skills with applied management and policy to achieve practical outcomes that have long-term benefits for species and biological communities. For landscape planners, the challenge is to design and implement land-use strategies that will ensure the conservation of natural resources in the face of competing demands for land use. This is especially important for government agencies responsible for the administration and management of large areas of land, but also relevant to community groups and individuals managing small parcels of land in fragmented landscapes subject to a wide range of land uses. For urban areas, it is much more of a challenge to create ecological corridors due to land use and ownership of land.

A possible solution to mitigate biodiversity loss in urban area is to ensure that the green spaces can provide refuge and resource areas for the focal species. Small patches or satellite nodes along the ecological network can be effective in providing habitats in which focal species can pause and/or breed, resulting in a higher survival rate in dispersing focal species, and hence more dispersing individuals in the network. In the corridors which are currently reserved for building development, pocket gardens, rooftop gardens and parks can be integral to the landscape design to prevent gaps in the connectivity network. Planting plans should also encourage addition of fruit trees and grains that the focal species eat.

Urban planners, landscape designers, and policy makers can profoundly affect how and where cities grow. If the Local Government Unit decides to add a road, a park, or housing tract, the use of the ENP will help accomplish the goal by maximizing the ecological integrity and minimizing land degradation. As such, the Green Lung Network Plan can be further improved using the ENP as this provides a data-driven basis for potentially effective green infrastructure for QC. Spatial pattern matters. It is no longer appropriate to plan based on totals or averages of prices, jobs, wages, parkland, bicycle paths, and so forth. Rather, the arrangement of land uses and habitats is crucial to planning, conservation, design management, and policy.

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