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Foto de la portada: Adult Morpho Butterfly (*Morpho helenor*) (photo © Jaime Navarrete R. & Joxual Araque).

Ecological corridor for lepidopterans in urban areas between Mokorón hill and UNAN, Managua.

Jaime Navarrete-Rivas[1] & **Joxual Araque Pérez**[2]

RESUMEN

CORREDOR ECOLÓGICO PARA LEPIDÓPTEROS EN ÁREAS URBANAS ENTRE EL CERRO MOKORÓN Y LA UNAN, MANAGUA.

Los bosques secos albergan una rica diversidad de Lepidopteros. Las comunidades de mariposas varían en abundancia, riqueza y composición de especies, influenciadas por el tamaño de los remanentes forestales y su conectividad. Conservar áreas con alta diversidad es crucial, dado que la fragmentación significativa puede reducir la cantidad de especies. Durante la estación seca, se realizó un estudio utilizando trampas Van Someren Rydon para capturar mariposas, colocadas en áreas con circuitos y sin circuitos, creados a partir de modelos de Least Cost Path y la Teoría de Circuito para evaluar la conectividad entre hábitats. Las especies capturadas se clasificaron como bioindicadoras. Los resultados mostraron que las áreas con menores resistencias y circuitos mantenían más individuos y especies. En contraste, las especies que se seleccionaron como bioindicadoras de áreas de perturbación eran más prevalentes en áreas con poca cobertura boscosa y desconectadas. Mantener la conectividad del hábitat es esencial para los flujos génicos, y los efectos negativos del aislamiento pueden mitigarse mediante corredores ecológicos.

Palabras clave: Corredor ecológico, Lepidoptera, Mariposas diurnas, fragmentación, Conservación, Indicadores.

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ABSTRACT

Dry forests harbor a rich diversity of Lepidoptera. Butterfly communities vary in abundance, species richness, and composition, influenced by the size of forest remnants and their connectivity. Conserving areas with high diversity is crucial, as significant fragmentation can reduce species numbers. The study was conducted during the dry season using Van Someren Rydon traps to capture butterflies, placed in areas with circuits and without circuits, created based on Least Cost Path models and Circuit Theory to assess habitat connectivity. The captured species were classified as bioindicators. The results showed that areas with lower resistances and circuits supported more individuals and species. In contrast, species selected as bioindicators of disturbed areas were more prevalent in regions with low forest cover and disconnected habitats. Maintaining habitat connectivity is essential for gene flow, and the negative effects of isolation can be mitigated through ecological corridors.

Keywords: Ecological corridor, Lepidoptera, diurnal butterflies, fragmentation, conservation Indicators.

INTRODUCTION

Dry Forest have a high diversity of lepidopteran species, and it is essential to understand their extinction or adaptation across different habitats (Castillo & Araque, 2017). Butterfly communities can differ in abundance, richness, and species composition within an ecosystem. These variations may depend on factors such as the size of forest remnants, their shape, structural complexity, and connectivity between forest fragments (Brown & Hutching, 1997).

It is necessary to conserve areas that maintain high levels of diversity over time. If there is significant fragmentation, the number of species may decline (Araque, 2023). Butterflies with a more generalist lifestyle and greater dispersal ability are less likely to decline in fragmented and intensively used landscapes compared to more specialized and sedentary species (Merckx & Van Dyck, 2019). In highly fragmented landscapes, natural selection may favor increased flight capacity in butterflies (Riva *et al*., 2023).

Proposing ecological corridors using circuits, resistances, costs, and distances is an effective strategy to mitigate the negative effects of species isolation in patches.

Ecological connectivity models have been developed in urban areas, where some approaches rely on identifying cost-distances through a cost-resistance matrix on a raster, using algorithms that determine the routes and quantify the minimum and maximum distance (accumulated cost) between previously selected cores (Etherington & Holland, 2013; Balbi *et al.*, 2020; Araque & Azofeifa, 2024).

These models identify areas where movements are facilitated and, conversely, areas where tree cover hinders movements (Braaker *et al.*, 2014). Among the available connectivity models are circuit theory (McRae *et al.*, 2008), individual-based models (Palmer *et al.*, 2011), and least-cost path analysis (Sawyer *et al.*, 2011). These models provide an effective way to understand the distribution and movement of species across different habitat types and land uses.

Among urban biodiversity representatives, Lepidoptera are an interesting taxon from a landscape ecology perspective. Although they are still relatively abundant in urban environments, their diversity is decreasing as urbanization increases (Merckx & Van Dyck, 2019). This document is an effort to understand genetic flows of species based on machine learning models, considering urban areas as sensitive to land use changes. The established model contributes to conservation and environmental education.

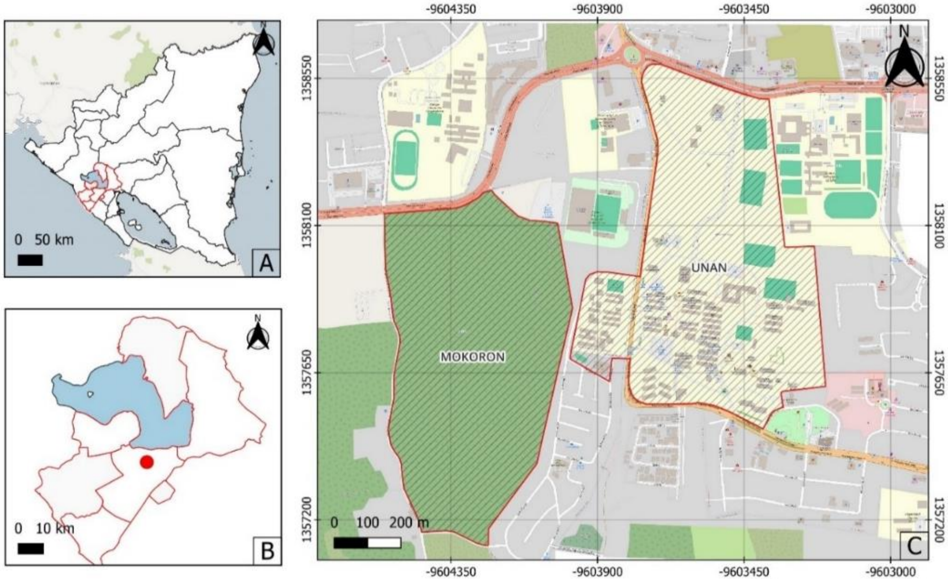

Figure 1. General Study Area: A) Nicaragua and its departments, B) Macro-location pertinent to the department of Managua (red point indicating the study area), C) Micro-location of the direct study area, showing the block between Mokorón Hill and UNAN-Managua. (own elaboration).

MATERIALS AND METHODS

The National Autonomous University of Nicaragua (UNAN, Managua) is located in the department of Managua, at coordinates 579024.8, 1337682.9 UTM-16N. To the east is Mokoron Hill, which consists of two main areas: the core zone (43 mz) and the buffer zone, which covers an estimated area of 972 mz, distributed as a peripheral ring around the core zone. The forest type is characterized as tropical dry forest according to Holdridge's classification.

Data Analysis: QGIS software, version 3.28 (Firenze), was used for the analysis of satellite images and the creation of maps. A cost-distance analysis was performed between the created core area and the sampled points using the LCP (Least Cost Path) algorithm (table. 1). This algorithm identifies areas that facilitate species movement according to land cover or land use by determining the least-cost route based on the configuration of the pixels in the raster under analysis (Braaker *et al*., 2014; Coulon *et al*., 2015; Araque & Azofeifa, 2024).

The possible connectivity network was calculated using R-Studio with the libraries ("LatticeExtra", "sp", "raster", "gdistance", "Tidyverse", "sf", "Terra", "mapview", "ggplot2", "corrplot"), based on MacRae's methodology involving Circuit Theory and gene flow (McRae, 2006; 2016). Three nodes were created, and links were established with respect to the centroid and observation points, calculating the least-cost distances between selected patches and species based on raster resistance, where areas with more vegetation present lower resistance to species movement (Table 1).

Supervised Classification: Satellite images from Planet.com for December 2023, code (L15-0533E-1093N), were downloaded. The raster resolution is 4.7m per pixel. A virtual raster was created in QGIS with bands R:2, G:1, and B:3 to perform supervised classification and generate a land use cover map. The virtual raster (band combination) and the output model were used for classification using Random Forest through the Dzetsaka classification plugin in QGIS.

The training was conducted using a shapefile layer in polygon format, assigning values to the classes for the regions of interest (ROI). The classification was validated using the Overall Accuracy method, following the methodology of Pollini, 2021. The following formula is used to calculate the overall accuracy of the confusion matrix:

$$\text{Overall accuracy}=\left[\frac{\text{Total classifications}}{\text{Total number of correctly classified pixels}}\right]\text{ x }100$$

Specimen Capture: The specimen capture was conducted during the dry season in December, January, and February 2024 using Van Someren Rydon traps. These traps are effective for collecting adult insects that spend most of their time in flight (figure 2). Combined with the appropriate attractant, they can capture the targeted species group. Seven traps were installed in each evaluated area (14 traps in total), baited with fermented fruits (banana, pineapple, and sugar) for 72 hours over three days in each area, aiming to attract frugivorous butterfly species from the Nymphalidae family (Dayli & Ehrlich, 1995).

The aforementioned family has diurnal habits, so the working period was from 8 am to 4 pm. Each trap was spaced approximately 80m to 100m apart, placed both within and outside the created nodes and resistances, covering most of the sampling points. The species have been classified as bioindicators based on bibliographic references for Papilionidae, Pieridae, and Nymphalidae, with an attached checklist of the authors who cite these species (Table. 3). All traps and collected individuals were geolocated using a Garmin eTrex SE GPS. Photographs were taken with a Canon EOS Rebel T7i camera, a Laowa 100mm lens, and an external flash.

Table 1. Values and characteristics assigned according to land use classification.

Classification	Code	Resitance		Characteristic
		LCP - QGIS	R-Studio	
Trees	1	1	1	Denser forested areas compared to other regions that appear to be covered with shrubs
Shrubsland	2	50	5	plant community characterized by vegetation dominated by shrubs, often also including herbs and grasses.
Bare Soil	3	600	60	Soils without vegetation cover due to deforestation, construction, earth removal, or roads.
Urbanization	4	800	80	Built areas, including hotels, houses, university and restaurants.

Figure 2. Species collection in the field, A) Species collected in V.S.R traps, B) Species captures by entomological net (own elaboration).

Identification: The identification of species from the Nymphalidae, Pieridae, and Papilionidae families was guided by the works of De Vries (1987, 1997), Lamas (2004), Maes (1999, 2006, 2007). Additionally, photographs were uploaded to the ***iNaturalist.org*** website for feedback from other experts. Photographic plates were created as a record for some of the captured species in this document.

Some of the tools used in this document for data capture were donated by **IdeaWild.org**.

RESULTS

The data were separated into two communities: Mokoron and UNAN-Managua, with a total of 47 species. It was found that the highest number of individuals captured was in the Mokoron area. However, both areas have very distinct species structures. Mokoron recorded a total of 37 species, while UNAN documented 23 species.

The areas show *Hamadryas februa* is the most abundant species with 43 individuals, followed by *Urbanus sp* with 18, *Hamadryas guatemalena* with 16 and *Archaeopreopona demophon* with 21 individuals (figure 4, a), in the UNAN area, the most abundant species are *Hamadryas februa* with 23 individuals, followed by *Taygetis uzza* with 14, *Vareuptychia themis* is also prevalent with 12 individuals (figure 4, b).

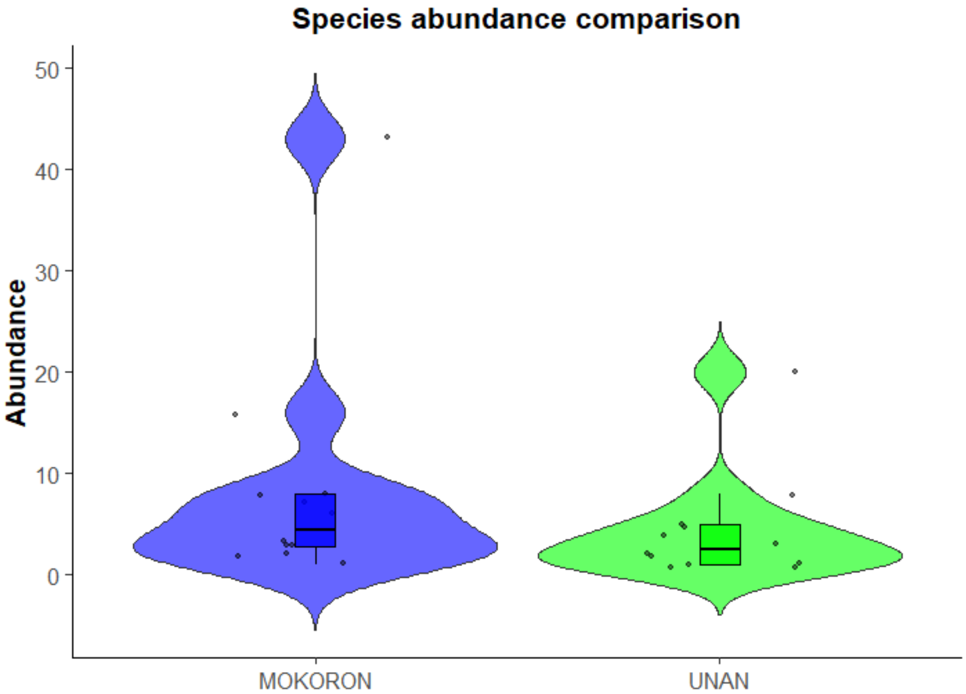

Figure 3. Abundance by study area, Mokoron (in blue) containing the highest number of individuals.

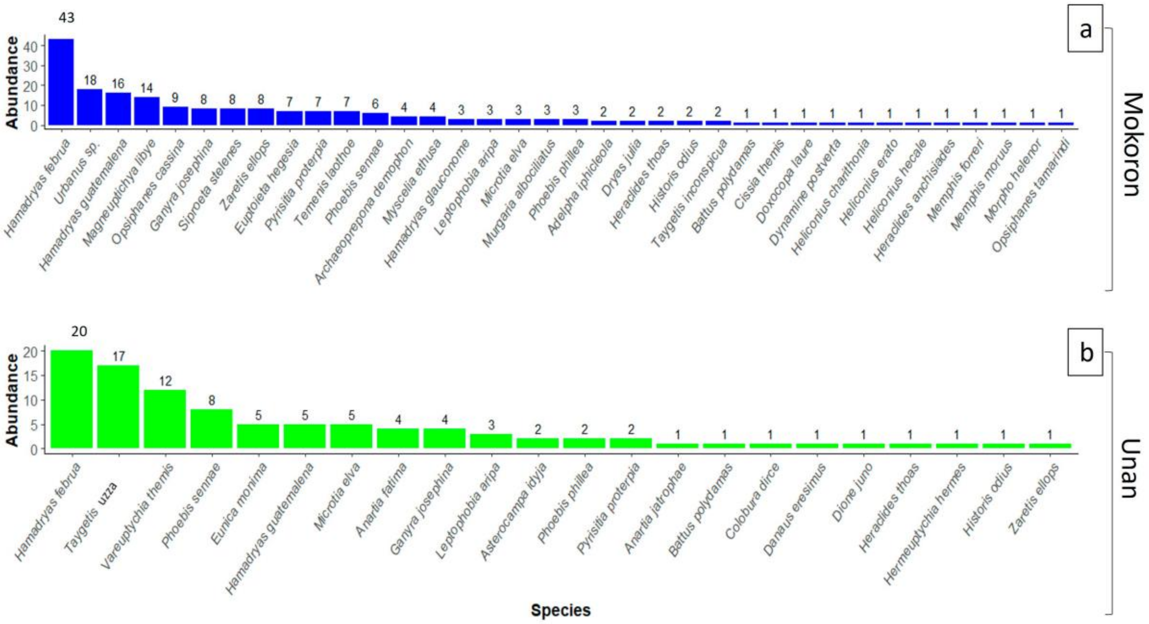

Figure 4. Distribution and abundance by Area: a) Mokoron (in blue) shows higher abundance and species, b) UNAN shows a lower number of species and abundance.

With the data collected on species and the separation of capture areas, the raster was classified, yielding an overall accuracy of 86.97% (a good result). The results of the metrics and supervised classification are shown in Table 2. It is observed that Mokoron has greater tree cover, being the segment with the highest number of individuals and species (figure 5, table 2). On the other hand, UNAN has fewer species.

Table 2. Confusion matrix, Metrics for calculating: Class Accuracy (PA), User's Accuracy (UA), and Overall Accuracy

Classification	Trees	Shrubs	Bare Soil	Urbanization	Total
Trees	7866	1837	2	0	9705
Shrubs	814	3503	9	0	4326
Bare Soil	3	9	3819	4	3835
Urbanization	0	2	0	2705	2707
Total	8683	5351	3830	2709	20573
PA%	90.5908	65.4644	99.7128	99.8523	86.97%

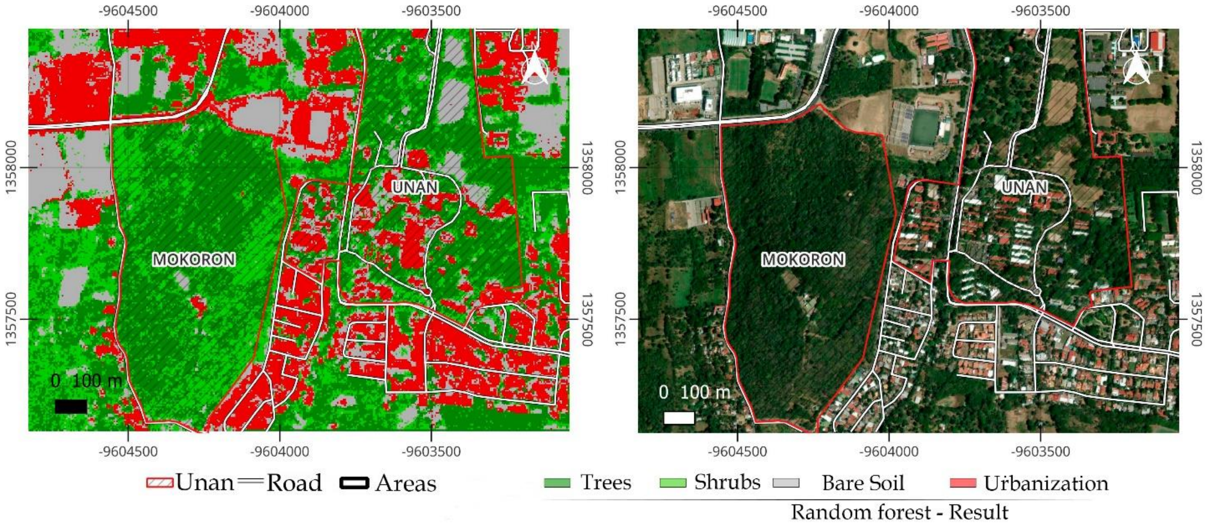

Figure 5. Image generation by supervised classification with 86.9% overall accuracy; a) classification created using the Dzetzaka plugin, b) raster used for the classification.

Before placing the traps, the core areas were divided into three. A model was created among the nodes using the raster layer classified in figure 5 to determine the circuit and flow of the species. Once the model was executed, areas with predicted higher and lower flow costs for the species were selected, and traps were placed both within and outside the generated circuits.

This was done to determine if there were different species or if the number of individuals was higher or lower according to the created circuits. In figure 6, an example is shown with traps placed outside and within the core areas.

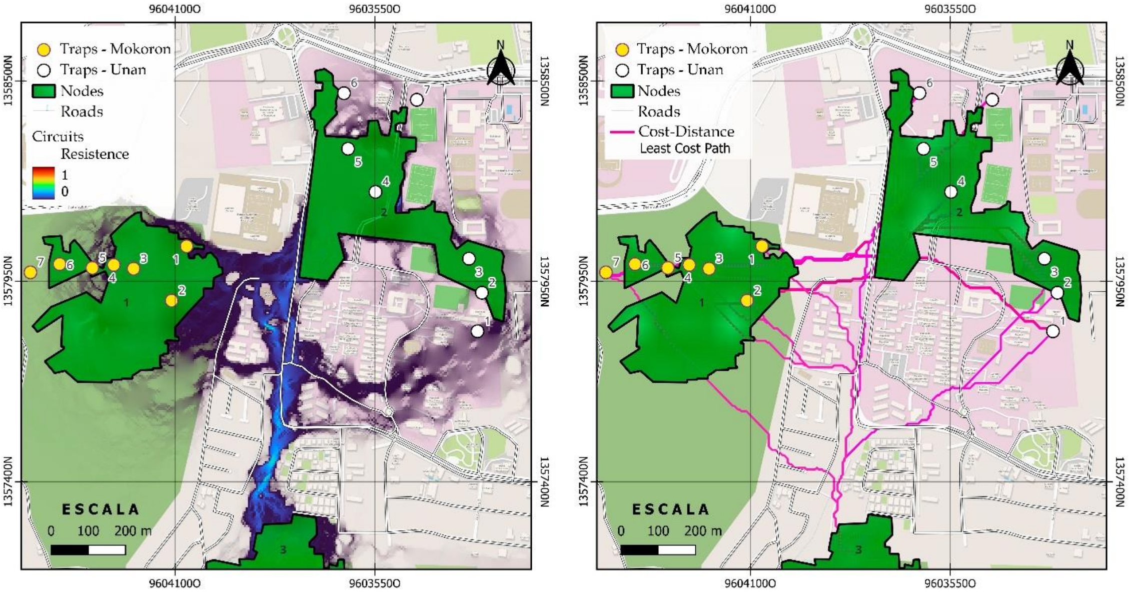

Figure 6. Connectivity through both models, a) Node and circuit model based on resistance, b) connectivity created from Least Cost Path.

Table 3. Bioindicator species found in the study as reference

Species	Bio-Indicator	References
Adelpha iphicleola	disturbance	Balam-Ballote, 2010
Anartia fatima	disturbance	Castillo & Araque, 2017. Legal, 2020
Anartia jatrophae	disturbance	Legal, 2020
Archaeoprepona demophon	conservation	González-Valdivia, 2016
Asterocampa idyja	unknown	-
Battus polydamas	unknown	-
Colobura dirce	disturbance	Pozo, 2006
Danaus eresimus	disturbance	Legal, 2020
Dione juno	disturbance	Balam-Ballote, 2010
Doxocopa laure	disturbance	Mélendez-Jaramillo, 2018
Dryas julia	disturbance	León-Cortés, 2019
Dynamine postverta	disturbance	González-Valdivia, 2011
Eunica monima	disturbance	Balam-Ballote, 2010
Euptoieta hegesia	unknown	Legal, 2020
Ganyra josephina	unknown	-
Hamadryas februa	disturbance	Balam-Ballote, 2010
Hamadryas glauconome	both	Legal, 2020
Hamadryas guatemalena	both	González-Valdivia, 2011
Heliconius charithonia	disturbance	Friesen, 2019
Heliconius erato	disturbance	Mélendez-Jaramillo, 2018
Heliconius hecale	disturbance	-
Heraclides anchisiades	unknown	-
Heraclides thoas	disturbance	Balam-Ballote, 2010

Species	Bio-Indicator	References
Hermeuptychia hermes	disturbance	Legal, 2020
Historis odius	disturbance	Pozo, 2006
Leptophobia aripa	unknown	Legal, 2020
Magneuptichya libye	unknown	Legal, 2020
Memphis forreri	conservation	González-Valdivia, 2011
Memphis moruus	both	González-Valdivia, 2011
Microtia elva	unknown	-
Morpho helenor	conservation	Balam-Ballote, 2010
Murgaria albociliatus	unknown	-
Myscelia ethusa	unknown	Friesen, 2019
Opsiphanes cassina	disturbance	González-Valdivia, 2011
Opsiphanes tamarindi	unknown	-
Phoebis marcellina	unknown	-
Phoebis philea	disturbance	Castillo & Araque, 2017. Balam-Ballote, 2010
Phoebis sennae	both	Balam-Ballote, 2010
Pyrisitia proterpia	disturbance	Balam-Ballote, 2010
Siproeta stelenes	disturbance	Balam-Ballote, 2010
Taygetis inconspicua	disturbance	González-Valdivia, 2011
Taygetis rufomarginata	disturbance	Vester, 2007(Mention the genus)
Taygetis uzza	disturbance	Vester, 2007(Mention the genus)
Temenis laothoe	disturbance	Pozo, 2006
Urbanus sp.	unknown	-
Vareuptychia themis	unknown	Legal, 2020
Zaretys ellops	unknown	Pozo, 2006

Note: The area with "unknown" species indicates that no citation records were found.

Within the corridors generated by both theoretical models, the structure of species is estimated based on the degree of disturbance or habitat (selected as bioindicators). This forms the basis for Table 3, which references authors citing these species. The aim is to determine the state of the butterfly community in terms of circuits and non-circuits.

Upon identifying the species as bioindicators, we proceeded to create figure 7, which illustrates their distribution by connectivity type. Areas labeled "With circuit" represent zones where species had greater opportunities for movement, according to the model generated in figure 6. These areas indicate efficient ecological corridors that facilitate species dispersal. Conversely, areas marked "No circuit" denote regions with higher resistance to movement, where ecological barriers limit species distribution and connectivity. This differentiation helps us understand how the butterfly community is structured in terms of accessible habitats and movement impediments.

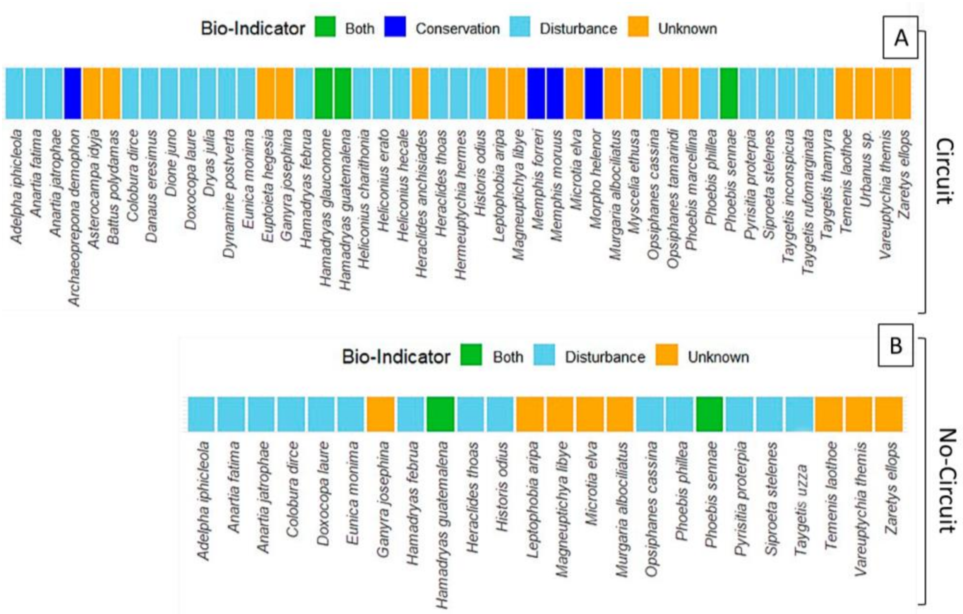

Figure 7. Bioindicator species found by type of generated ecological connectivity.

Figure 7 reveals that in areas without circuits, there is a higher number of species from disturbed habitats, with representative genera such as *Adelpha*, *Anartia*, *Colobura*, *Doxocopa*, *Eunica*, *Hamadryas*, *Historis*, *Murgaria*, and others. This highlights the importance of implementing conservation measures in these zones to mitigate the effects of habitat disturbance. In contrast, areas with circuits show greater species richness and variability, featuring genera from conserved habitats like *Archaeoprepona*, *Memphis,* and *Morpho*. This emphasizes the crucial role of maintaining ecological corridors to support the diversity and health of butterfly populations.

The following are some species that were collected in the area (photo © Jaime Navarrete R. & Joxual Araque).

IDEA WILD

Morpho helenor (Cramer, 1776)

Caligo telamonius memnon (Felder & Felder, 1867)

Archaeoprepona demophon (Linnaeus, 1758)

Historis odius dious (Lamas, 1995)

Heraclides thoas (Linnaeus, 1771)

Battus polydamas (Linnaeus, 1758)

Euptoieta hegesia (Cramer, 1779)

Danaus eresimus (Cramer, 1777)

Zaretis ellops (Ménétriés, 1855)

Hamadryas guatemalena (Bates, 1864)

DISCUSSION

The raster classification achieved an overall accuracy of 86.97%, illustrating reliable habitat connectivity models. The classification revealed that Mokoron, with its higher tree cover, supports a more diverse butterfly population. This emphasizes the critical role of tree cover in maintaining ecological corridors, which facilitate species dispersal and reduce the impacts of habitat fragmentation, as noted by McRae & Beier (2007).

The use of data classification and cleaning is essential. The *Dzetsaka* plugin is an easy-to-use machine learning tool (Andrade *et al*., 2024). However, after classification, it is necessary to clean the data to achieve better results. In our ecological connectivity analysis, we observed a strong correlation with the *in-situ* area, prompting us to place traps. The results showed that due to low coverage in many areas with high resistance circuits, species numbers decreased, while those considered to inhabit disturbed areas increased (figure 6).

The presence of ecological corridors plays a significant role in facilitating species diversity and movement between habitats. Studies have shown that corridors can mitigate the effects of habitat fragmentation by providing pathways for dispersal and gene flow (Gilbert-Norton *et al*., 2010). The dominance of disturbance bioindicators such as *Adelpha iphicleola*, *Anartia fatima*, and *Colobura dirce* is more prevalent in disturbed and disconnected areas. These species are often adapted to thrive in environments where human activities have altered the landscape (Fahrig, 2003).

Theoretically, increasing or diversifying the number of tree species could enhance the diversity of Lepidoptera species (Haddad *et al*., 2015). The lower representation of conservation bioindicators highlights the need for conservation efforts aimed at protecting and restoring these habitats. Therefore, the design of figure 5 will help plan areas that need reforestation or diversification at the plant species level (Araque, 2023; Araque & Azofeifa, 2024).

Some species, such as *Hamadryas glauconome* and *Phoebis sennae*, are found in both disturbed and conserved habitats, indicating a level of adaptability to various environmental conditions. This adaptability can be crucial for the resilience of butterfly populations in fragmented landscapes, as it allows for greater flexibility in habitat use (Haddad, 1999; McRae & Beier, 2007).

CONCLUSION

The study highlights the importance of conserving areas to maintain lepidopteran diversity, particularly in dry and urban forest ecosystems. Habitat fragmentation significantly impacts butterfly communities, as species can gradually decline in areas with high resistance and lack of connectivity. This underscores the need to maintain habitat connectivity to facilitate genetic flow and mitigate the negative effects of isolation.

The implementation of ecological corridors using models such as Least Cost Path and Circuit Theory can be an effective strategy to enhance species movement and dispersal. The findings emphasize the role of tree cover in supporting diverse butterfly populations and the critical need for conservation efforts to focus on creating and maintaining these corridors. The successful use of bioindicators in this study demonstrates their value in assessing habitat quality and connectivity.

Overall, the research provides a solid foundation for future conservation initiatives, highlighting the use of algorithmic techniques to understand and manage ecological connectivity in fragmented urban landscapes. However, the collection period was only four months (a short period of time), and the dry season may have influenced the population trends of species in the study. During the rainy season, there is a greater likelihood of collecting a higher number of species (Yoshimoto et al., 2021). It is recommended to conduct an analysis during the rainy season for a more comprehensive understanding of species dynamics.

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