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Environmental Science and Development

B.S. in Environmental Science and Development

Special Graduation Project

Comparing nymphalid butterfly diversity in a banana plantation with other ecosystems in Colón, Honduras

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Abstract

Butterflies are widely recognized as bioindicators due to their sensitivity to environmental changes. This study evaluated the diversity of Nymphalid butterflies in a banana plantation with other ecosystems in Colón, Honduras. A survey of butterflies was conducted within the plantation and other areas in Colón, including a natural forest and an urban area. The study compared butterfly diversity across these four ecosystems and proposed butterfly species that can serve as bioindicators of environmental health. Sampling was conducted using baited cylindrical traps. The Shannon index was used to provide a measure of biodiversity within each ecosystem, while Chao's estimator was used to estimate true species richness. The results revealed clear differences in species richness and community structure among ecosystems. The suburban area with orchards exhibited the highest species richness (17 species observed, 41 estimated) representing 60% of the total diversity found in the study, followed by the humid forest (16 species observed, 22 estimated; 57%), the urban area (10 species observed, 14 estimated; 35%), and finally the banana plantation (7 species observed, 15 estimated), which accounted for just 25% of the total diversity. This ecosystem showed the greatest overall dominance, another indicator of biodiversity loss. Species in the gender *Archaeoprepona, Manataria*, *Morpho* and *Taygetis* were proposed as indicators of healthier ecosystems, being much more abundant in the natural forest ecosystem. In contrast, one species (*Hermeuptychia hermybius),* found abundantly in the banana plantation and town*,* was proposed as an indicator of degraded environments. This study provided insights into the effects of agricultural practices on biodiversity and highlighted the potential value of butterflies as indicators of ecological health in agricultural ecosystems.

Keywords: Habitat loss, land-use change, Lepidoptera, sustainable land management, tropical agroecosystems

Resumen

Las mariposas son ampliamente reconocidas como bioindicadores debido a su sensibilidad a los cambios ambientales. Este estudio evaluó la diversidad de mariposas Nymphalidae en una plantación de banano y otros ecosistemas en Colón, Honduras. Se realizó un muestreo de mariposas dentro de la plantación y en otras zonas de Colón, incluyendo un bosque natural y un área urbana. El estudio comparó la diversidad de mariposas entre estos cuatro ecosistemas y propuso especies que pueden servir como bioindicadores de la salud ambiental. El muestreo se llevó a cabo utilizando trampas cilíndricas cebadas. Se utilizó el índice de Shannon para medir la biodiversidad dentro de cada ecosistema, mientras que el estimador de Chao se usó para calcular la riqueza real de especies. Los resultados revelaron diferencias claras en la riqueza de especies y la estructura de la comunidad entre los ecosistemas. El área suburbana con huertos mostró la mayor riqueza de especies (17 especies observadas, 41 estimadas), representando el 60% de la diversidad total encontrada en el estudio, seguida por el bosque húmedo (16 especies observadas, 22 estimadas; 57%), el área urbana (10 especies observadas, 14 estimadas; 35%) y, finalmente, la plantación de banano (7 especies observadas, 15 estimadas), que representó solo el 25% de la diversidad total. Este último ecosistema mostró la mayor dominancia general, otro indicador de pérdida de biodiversidad. Se propusieron especies de los géneros *Archaeoprepona*, *Manataria*, *Morpho* y *Taygetis* como indicadoras de ecosistemas más saludables, ya que fueron mucho más abundantes en el ecosistema de bosque natural. En contraste, una especie (*Hermeuptychia hermybius*), encontrada en abundancia tanto en la plantación de banano como en el pueblo, fue propuesta como indicadora de ambientes degradados. Este estudio proporcionó información sobre los efectos de las prácticas agrícolas en la biodiversidad y destacó el valor potencial de las mariposas como indicadores de la salud ecológica en ecosistemas agrícolas.

Palabras clave: Agroecosistemas tropicales, Lepidóptera, manejo sostenible del territorio, modificación de hábitat, pérdida de hábitat

Introduction

In the context of modern agriculture, the Green Revolution brought a significant increase in agricultural productivity, driving the economy and establishing agriculture as a pillar of economic development. Today, this sector is essential for food production and other ecosystem services crucial to human well-being. Agriculture is fundamental to the economy; it serves as the backbone of a country's economic system and represents national productivity (Carpio Santos, 2018). However, this growth also led to the expansion of the agricultural frontier. Today, almost half of the world's habitable land—44%, around 48 million km^2—is used for agriculture, with approximately 15% of this land classified as croplands, dedicated to growing crops for human consumption, animal feed, and non-food products (Ritchie y Roser, 2019). Globally, banana plantations span over 5 million ha, highlighting the importance of bananas in global agriculture. In Honduras, banana plantations occupy a significant land area, with approximately 112,000 ha dedicated to banana production (Hartinger et al., 2024).

The expansion of the agricultural frontier has resulted in the conversion of vast forests into productive agricultural lands and pastures, leading to massive habitat loss for many species (Herrera-Feijoo, 2024). The impact of this change is evident in the degradation of ecosystems and the related ecosystem services, a consequence of current agricultural practices. Modern intensive agriculture has led to soil degradation, biodiversity loss, and habitat alteration due to the excessive use of pesticides and fertilizers. The use of fertilizers and pesticides can harm the soil, nearby streams and rivers, and can affect local biodiversity and the related ecosystem services. As the agricultural frontier expands, more natural ecosystems and forests are destroyed. The indiscriminate use of agricultural chemicals has severely affected biodiversity, a key element in maintaining ecological balance and providing essential ecosystem services such as pollination (Armijos Leon, 2015).

Due to their sensitivity to environmental changes, butterflies have been used as bioindicators in various studies assessing ecosystem health in agricultural plantations and natural areas. Research by Brown y Freitas (2000) and Ribeiro et al. (2009) demonstrates that butterfly communities, particularly within the Nymphalidae family, respond sensitively to habitat alterations, making them excellent indicators of habitat quality due to their complex interactions with host plants and environmental resources. Similarly, studies conducted in intensive agriculture, such as tropical oil palm monocultures and cocoa plantations, have established a relationship between butterfly abundance and habitat quality, providing an effective tool for assessing the environmental impacts of intensive agriculture on ecosystems (Schulze et al., 2004; Thomas, 2005). Nonetheless, it was not found in the literature studies of butterflies in banana plantations.

Despite the ecological importance of butterflies as bioindicators, pollinators and responsible for ecosystem services, there is a notable lack of studies focusing on their diversity in banana plantations. This absence limits the understanding of how intensive monocultures affect local biodiversity, particularly in tropical regions like Colón, Honduras. Nymphalid butterflies are especially relevant for ecological monitoring because their presence and abundance can reflect subtle changes in habitat quality, resource availability, and environmental stress. Documenting their diversity in human-modified landscapes contributes to conservation science by identifying species at risk, guiding habitat restoration efforts, and informing policies for more sustainable agricultural practices. In this context, the present study aims to fill this gap by comparing butterfly diversity in a banana plantation and others ecosystems in Colón, Honduras, in order to assess the ecological impacts of land use and support biodiversity monitoring in the region.

Based on this issue, this evaluation aimed to a) determine nymphalid butterfly species richness in a banana plantation and in other ecosystems: a humid forest, an urban area, and a suburban area; b) compare biodiversity indices for the banana plantation and the other ecosystems; and c) identify nymphalid butterfly species that may serve as indicators of ecosystem quality.

Methods

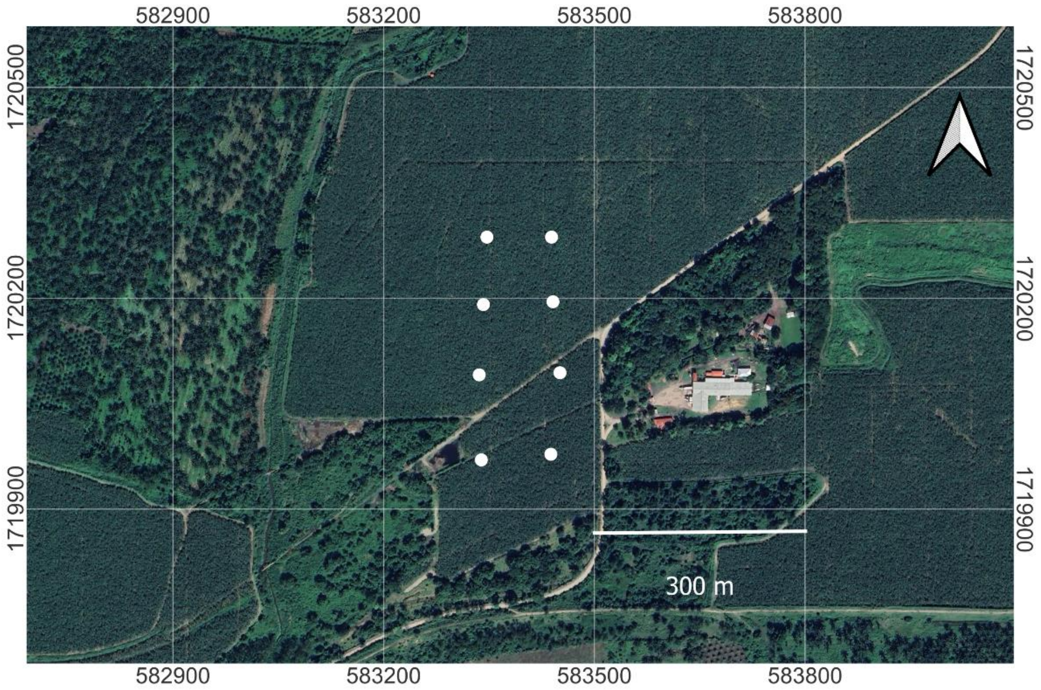
Characterization of Study Sites and Butterfly Sampling Design

Study Site

The main study site was one of Dole's banana plantations in Sabá, Colón, Honduras, as shown in Figure 1. Sabá, located in the Colón Department of Honduras at coordinates 15°31′05″N, 86°13′50″W, lay approximately 80 m.a.s.l. The region experiences a tropical monsoon climate with average temperatures ranging from 21 to 26 °C throughout the year. Rainfall is significant, with an average annual precipitation of about 1,691 mm spread over approximately 209 rainy days, predominantly occurring between May and November.

Figure 1

Butterfly sampling locations (white dots) at Dole's banana plantation in Sabá, Colón

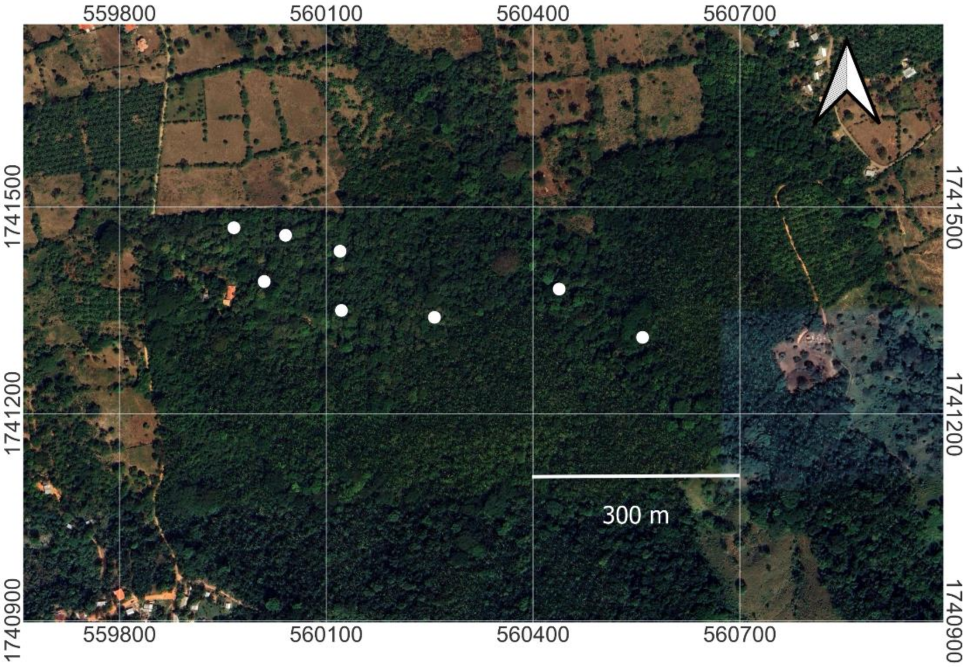


This area was representative of tropical agroecosystems, where intensive agriculture, particularly banana production, had significantly altered local biodiversity. It is characterized by practices such as monoculture, periodic pesticide application, irrigation systems, and the construction of channels for transporting fruit. However, there are also small green areas with trees and vegetative cover. During the sampling period, the climate was predominantly rainy, with sunnier conditions observed toward the end of the data collection.

The humid-forest study site was located at Santuario Aves Honduras "El Carmen" at coordinates 15°44'47"N, 86°26'09"W (Figure 2). This site retains natural characteristics with minimal human interventions, including trails, ecotourism, and a small cacao plantation.

Figure 2

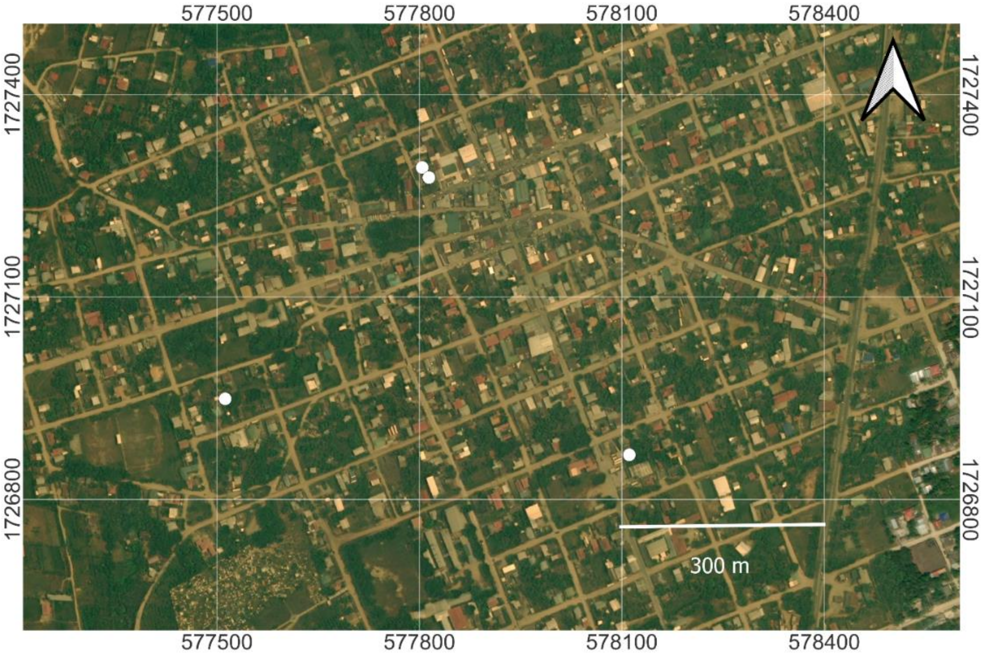
Butterfly sampling locations (white dots) at humid forest in Santuario Aves Honduras



The final treatment, the town ecosystem, was subdivided into two subcategories due to notable differences in environmental conditions among the sampling sites. The first subcategory located at coordinates 15°37'14"N, 86°16'20"W, referred to as Urban Town (Figure 3). It included traps placed in areas with predominantly urban features, such as sidewalks near commercial establishments, high vehicular and pedestrian traffic, and frequent waste or trash burning. Despite these urban pressures, roadsides and gardens also contained trees and patches of vegetation.

Figure 3

Butterfly sampling locations (white dots) at urban area in Sonaguera, Colón



The second subcategory was a suburban area, so named because it included orchards and had a more natural ecosystem than the urban treatment (Figure 4). This area located at coordinates 15°36'38"N, 86°16'56"W, featured numerous trees, gardens, and fruit orchards, and considerably less vehicular and pedestrian traffic. Although there were houses and human intervention, most of the area had vegetation, and high biodiversity was observed during sampling.

Figure 4

Butterfly sampling locations (white dots) at suburban/orchards in Sonaguera, Colón

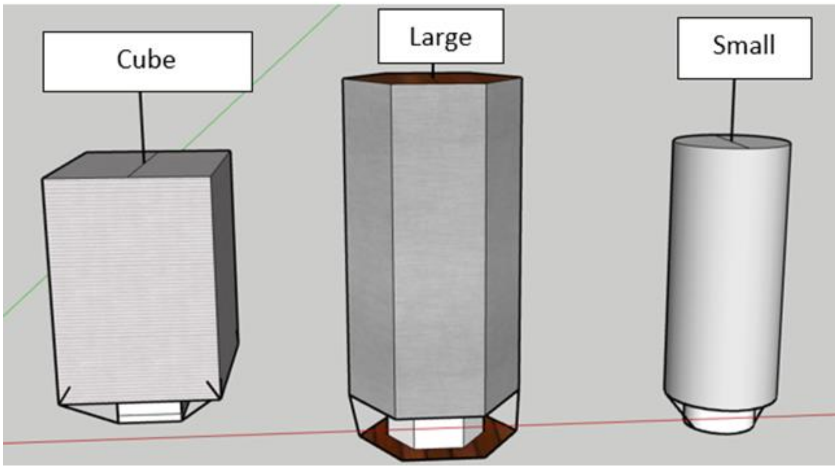
Sampling was carried out in the humid forest and the town (including both suburban and urban areas) from January 7th to 12th, while the banana plantation was sampled from January 8th to 13th.

Study Design

The primary focus of this research was to examine the relationship between conventional agricultural practices and the biodiversity of butterflies in the family Nymphalidae. To achieve this, two variables were selected: butterfly biodiversity (dependent variable) and the ecosystem class (independent variable). For this study, van Someren-Rydon traps were used, with three designs (Figure 5). Such traps have proven to be efficient in capturing canopy-dwelling species, are easy to use, and are inexpensive to produce. As described by Diez-Canseco (2007), these traps are generally made from two concentric rings covered with tulle or another light fabric, forming a cylindrical shape that capture butterflies attracted to fermented bait placed on a plate near the opening at the bottom. After feeding at the bait, the butterflies tend to fly upwards and remain inside the trap. In addition to traps of two different sizes, there were also traps with a cubic shape (Figure 5), but it was expected the trap types to all work similarly, as the area for bait placement, and the trap entrances were all the same size.

Figure 5

Three trap designs used in the study



To ensure adequate sampling, a design involving the placement of eight traps with fermented banana bait was implemented in each of the ecosystem treatments, except for the suburban and urban areas, each of which had four bait traps and the humid forest which had seven traps due to a damaged trap during sampling. This method is effective for attracting and capturing butterflies in biodiversity studies conducted in tropical environments, minimizing disturbance to the surroundings and enabling the collection of a representative sample of species (Devries et al., 2010). The use of traps facilitated an objective inventory and helped establish the relationship between butterfly biodiversity and the evaluated ecosystems (Hughes et al., 2000).

The traps varied across sites (this was accounted for in statistical analysis) and were systematically and arbitrarily placed at distances of up to 100 m apart, maintaining a minimum separation of 30 m to avoid competition among traps and to maintain independence of samples. The traps were suspended using cords looped over high tree branches to maximize elevation and sunlight exposure, typically ranging between 2 to 4 m above ground. Each cord was tied to a nearby tree trunk, allowing the traps to be easily lowered for the periodic removal of live butterflies. Data were collected over 5 days. The first day was used to place the traps, and on the second day, they were checked, and the data was recorded. The traps remained active for 24 h before each data collection session, with the bait replenished depending on the condition of the bait. Trap types used in each study site varied but were recorded in case this variation caused unacceptable bias (Table 1). This procedure was applied across all the ecosystems studied (Martínez et al., 2022).

Table 1

Trap types used in each ecosystem

Treatment/ecosystem	Cube	Large	Small
Banana plantation	2	3	3
Humid Forest		4	4
Urban Town	4		
Suburban/Orchard		4	

Biodiversity Assessment and Statistical Analysis

Statistical and Other Types of Analysis

Data analysis was conducted using ANOVA (Analysis of Variance) to assess whether significant differences existed in biodiversity indicators (species richness observed, Shannon Index) among the Dole plantation, the natural forest, and the residential areas. To ensure the validity of this analysis, four key assumptions were considered: (1) observations had to be independent; (2) the dependent variable had to follow a normal distribution within each group; (3) variances among groups had to be homogeneous; and (4) the dependent variable had to be measured on a continuous scale (Zar, 2013). Since some variability in group variances was detected, the Brown-Forsythe correction was applied to the ANOVA. This adjustment provides a more robust test in the presence of unequal variances by reducing sensitivity to heteroscedasticity, helping to maintain the reliability of the results even when the assumption of homogeneity is moderately violated.

To measure biodiversity, the Shannon index was calculated for each trap (Fang et al., 2024). Additionally, the Chao estimator was used to obtain a robust estimation of the total species richness of Nymphalidae butterflies for each ecosystem. This methodology has been widely applied in biodiversity studies (Chao et al., 2005), enabling assessment of inventory completeness. A significance level (*p*) of 0.05 was employed to determine the statistical significance of the results.

Species accumulation curves were generated to compare observed species richness across treatments. This method allowed for an evaluation of whether the sampling efforts were sufficient to represent the area's diversity and facilitated standardized comparisons of species richness across ecosystems (Colwell y Coddington, 1994). For generating the curves, the software Estimates 9.10® was used, simulating random sampling by resampling the existing data 100 times to ensure a more accurate representation of the species accumulation. In addition, the Chao estimator and the Shannon diversity index were calculated using the software Estimates 9.10® and for the ANOVA analysis, the software JASP® was employed to perform statistical comparisons among ecosystems.

Identification of Indicator Species for Ecosystem Quality

Identification

For species identification, the digital tool iNaturalist® was used. This tool is widely utilized by experts worldwide, who validate species identification. Additionally, identifications were verified using field guides (Glassberg, 2018; Mateo et al., 2022). Photographs of the captured specimens were taken for identification, and species were also collected under the ICF ("Instituto Nacional de Conservación y Desarrollo Forestal") for deposit to the Zamorano University entomology collection.

The approach for proposing indicator species of healthy forest ecosystems consisted of selecting those that were notably more abundant in the humid forest when compared to the other ecosystems. In the case of the indicators of degraded ecosystems, the process was similar, where the most abundant species in the intervened ecosystems qualified as proposed indicator species if they were uncommon or absent in the forest ecosystem.

Results

Dole's Banana Plantation

This site utilized eight traps over a 120-hour period, but only 21 individuals representing seven species were collected (Table 2). *Hermeuptychia hermybius* was the most common. Regarding the species accumulation curve, the asymptote was not reached. The curve shows the estimated number of species detected over time, based on data collected from eight traps placed for approximately five days each (Figure 6). In Figure 6, the x-axis, labeled "Trap Weeks," represents the cumulative sampling effort—each unit corresponds to one trap operating for about one week. The solid red line indicates the estimated species richness, while the dashed lines represent the 95% confidence interval.

Table 2

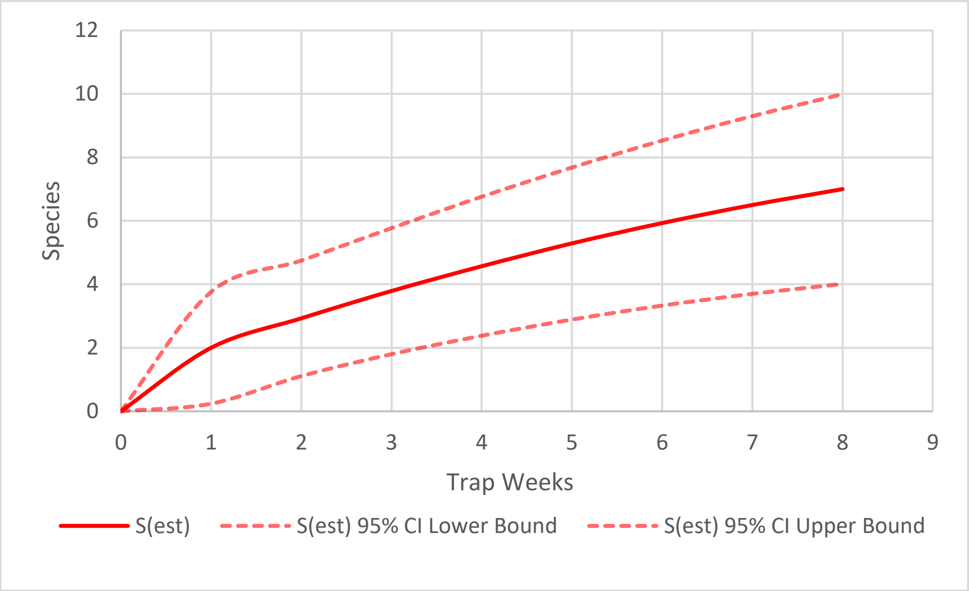
Richness and abundance of nymphalid butterflies in the banana plantation

Species	T1	T2	T3	T4	T5	T6	T7	T8	Total
Anaea pithyusa						1			1
Hamadryas feronia					1			1	2
Hermeuptychia hermybius	1	2	1	2	1	1	2	2	12
Historis odius	1								1
Opsiphanes fabricii			2				1		3
Smyrna blomfildia		1							1
Taygetis inconspicua/uzza								1	1
Accumulation of species	2	3	4	4	5	6	6	7	21

Note: T = Trap. Each column represents a specific trap and the number of butterflies captured during the sampling period, while each row corresponds to a specific species. The final row indicates the cumulative total of butterfly species recorded over sampling time, illustrating how the addition of new traps contributed to detecting new species and enhanced species accumulation, and the final column shows the total number of individuals recorded for each species

Figure 6

Accumulation of nymphalid butterflies species richness in the banana plantation



Humid Forest

Using seven traps in this treatment, due to a damaged trap during sampling, a total of 83 nymphalid butterflies were captured, comprising 16 species (Table 3). Notably, *Archaeoprepona amphimachus* was the most frequently captured species, appearing in all seven traps with a total of 15 individuals, indicating a strong presence across the sampled habitat. On the other hand, some species such as *Napeogenes tolosa* and *Anaea eurypyle* were represented by a single individual each. Regarding the accumulation curve, the curve continues to rise and does not reach an asymptote, suggesting that additional species remain undetected (Figure 7).

Table 3

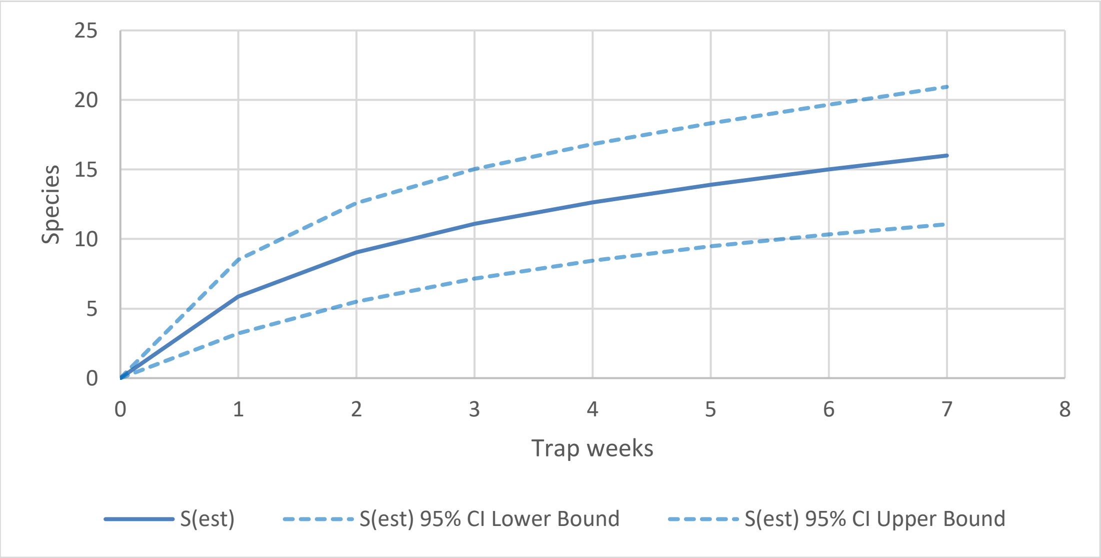
Richness and abundance of nymphalid butterflies in the humid forest

Species	T1	T2	T3	T4	T5	T6	T7	Total
Anaea eurypyle					1			1
Archaeoprepona amphimachus		1	2	3	4	2	1	15
Archaeoprepona demophon		2	1	3				6
Archaeoprepona demophoon						1		1
Caligo eurilochus			2		2			4
Caligo telemachus		1						1
Colobura dirce			1	2	1	2	2	8
Historis acheronta	2						1	3
Manataria maculata				8	1	2		11
Morpho helenor	1	2		4	3	1		11
Napeogenes tolosa			1					1
Opsiphanes bogotanus							1	1
Opsiphanes fabricii	1		2				4	7
Pareuptychia metaleuca		2						2
Smyrna blomfildia					2			2
Taygetis inconscpicua/uzza	1		3	1	5	1		11
Accumulation of species	4	8	11	12	14	15	16	85

Note: T = Trap. Each column represents a specific trap and the number of butterflies captured during the sampling period, while each row corresponds to a specific species. The final row indicates the cumulative total of butterfly species recorded over sampling time, illustrating how the addition of new traps contributed to detecting new species and enhanced species accumulation, and the final column shows the total number of individuals recorded for each species.

Figure 7

Accumulation of nymphalid butterflies species richness in the humid forest



Town

Subtreatment: Urban Town

For the urban town treatment four traps were placed under urban conditions, such as gardens of establishments and homes. A total of 10 species and 26 individuals were captured (Table 4). Despite the lower number of traps, more species and individuals were recorded compared to the banana plantation. Some species overlapped between the two treatments. Regarding the species accumulation curve, the curve does not reach an asymptote, indicating that additional sampling could yield more species (Figure 8).

Table 4

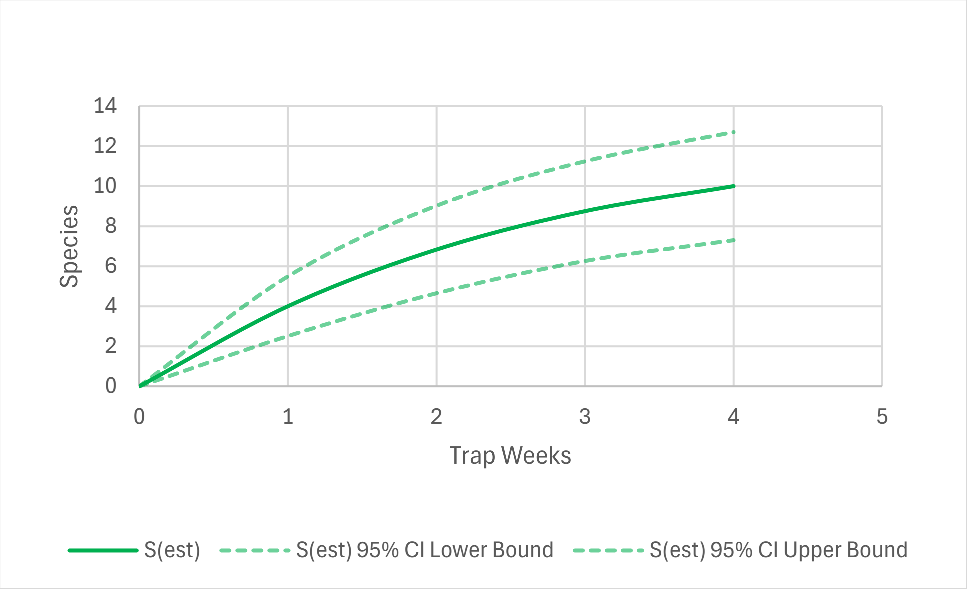
Richness and abundance of nymphalid butterflies in the urban town area

Species	T1	T2	T3	T4	Total
Archaeoprepona amphimachus	1				1
Colobura dirce	1			2	3
Hamadryas guatemalena		1			1
Hermeuptychia canthe	1	1			2
Hermeuptychia hermybius		8			8
Historis acheronta				1	1
Historis odius	1	2			3
Magneuptychia libye	1				1
Opsiphanes fabricii	2	1	1		4
Smyrna blomfildia		1		1	2
Accumulation of species	6	9	9	10	26

Note. T = Trap. Each column represents a specific trap and the number of butterflies captured during the sampling period, while each row corresponds to a specific species. The final row indicates the cumulative total of butterfly species recorded over sampling time, illustrating how the addition of new traps contributed to detecting new species and enhanced species accumulation, and the final column shows the total number of individuals recorded for each species.

Figure 8

Accumulation of nymphalid butterflies species richness in the urban town



Subtreatment: Suburban/Orchards

With only four traps deployed in the suburban subtreatment 17 species were collected, totaling 72 individuals, one more species than the humid forest, but with a lower effort and a lower number of individuals (Table 5). Thus, the suburban/orchard and humid forest treatments exhibited a similar number of species detected and even shared a considerable portion of them. Only seven species were shared between these ecosystems: *Archaeoprepona amphimachus*, *Archaeoprepona demophon, Archaeoprepona demophoon*, *Colobura dirce*, *Historis acheronta*, *Opsiphanes fabricii*, and *Smyrna blomfildia*. These species were the most common across treatments, suggesting they are more resilient to habitat changes and human intervention. Additionally, some species were unique to this ecosystem, such as *Eunica tatila, Callicore texa, Temenis laothoe,* and *Myscelia cyaniris*. The accumulation curve follows a similar pattern to that of the humid forest, also failing to reach the asymptote (Figure 9).

Table 5

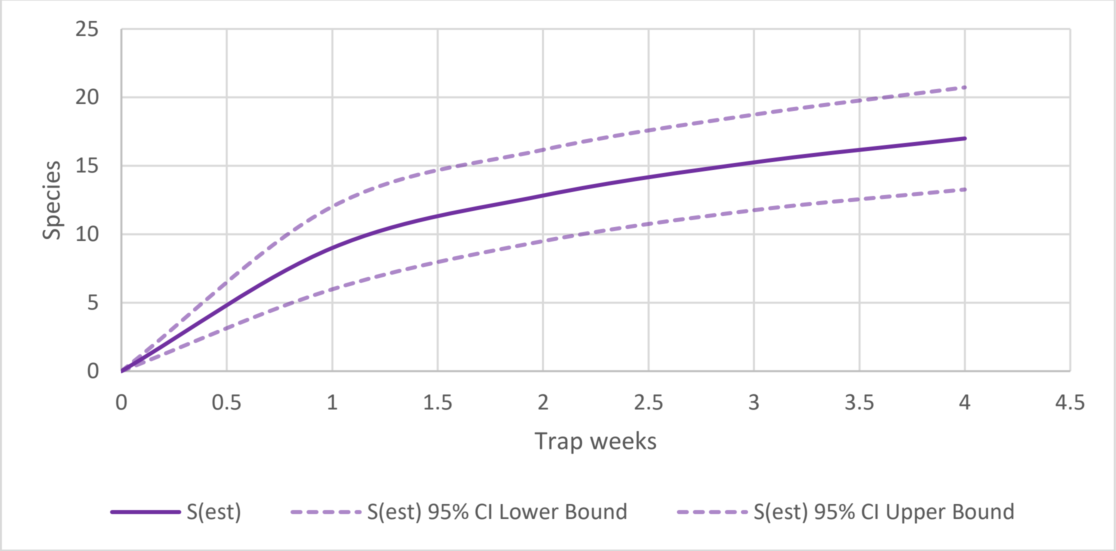
Richness and abundance of nymphalid butterflies in the suburban/orchards area

Species	T5	T6	T7	T8	Total
Archaeoprepona amphimachus	4	2		1	7
Archaeoprepona demophon		1			1
Archaeoprepona demophoon		1			1
Callicore texa			1		1
Colobura dirce		2		2	4
Eunica tatila			1		1
Hamadryas februa	2	1	2	1	6
Hamadryas feronia		1	3	1	5
Hamadryas guatemalena	1			1	2
Hermeuptychia canthe	1				1
Hermeuptychia hermybius	3	4	4	2	13
Historis acheronta		5	2	4	11
Magneuptychia libye		3		1	4
Myscelia cyaniris		1			1
Opsiphanes fabricii	2	1	2	5	10
Smyrna blomfildia		2	1		3
Temenis laothoe				1	1
Accumulation of species	6	14	16	17	72

Note. T = Trap. Each column represents a specific trap and the number of butterflies captured during the sampling period, while each row corresponds to a specific species. The final row indicates the cumulative total of butterfly species recorded over sampling time, illustrating how the addition of new traps contributed to detecting new species and enhanced species accumulation, and the final column shows the total number of individuals recorded for each species

Figure 9

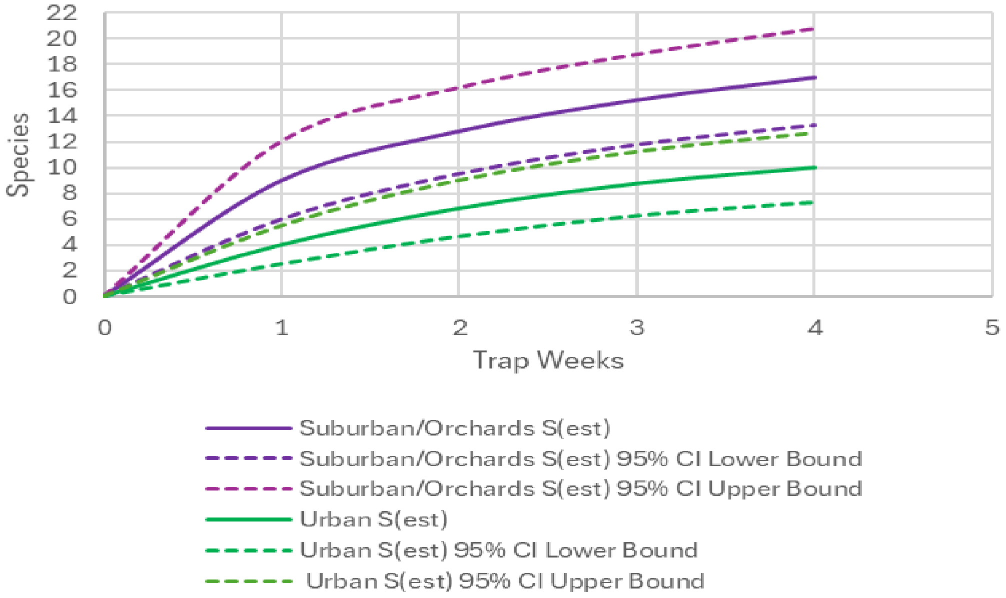
Accumulation of nymphalid butterflies species richness in the suburban/orchards



In Figure 10, the species accumulation curves illustrate the rationale for subdividing the town treatment into two distinct categories: urban and suburban/orchard areas. The biodiversity differences between these environments are evident, as reflected by the non-overlapping 95% confidence intervals, which indicate statistically significant variation between the two subtreatments.

Figure 10

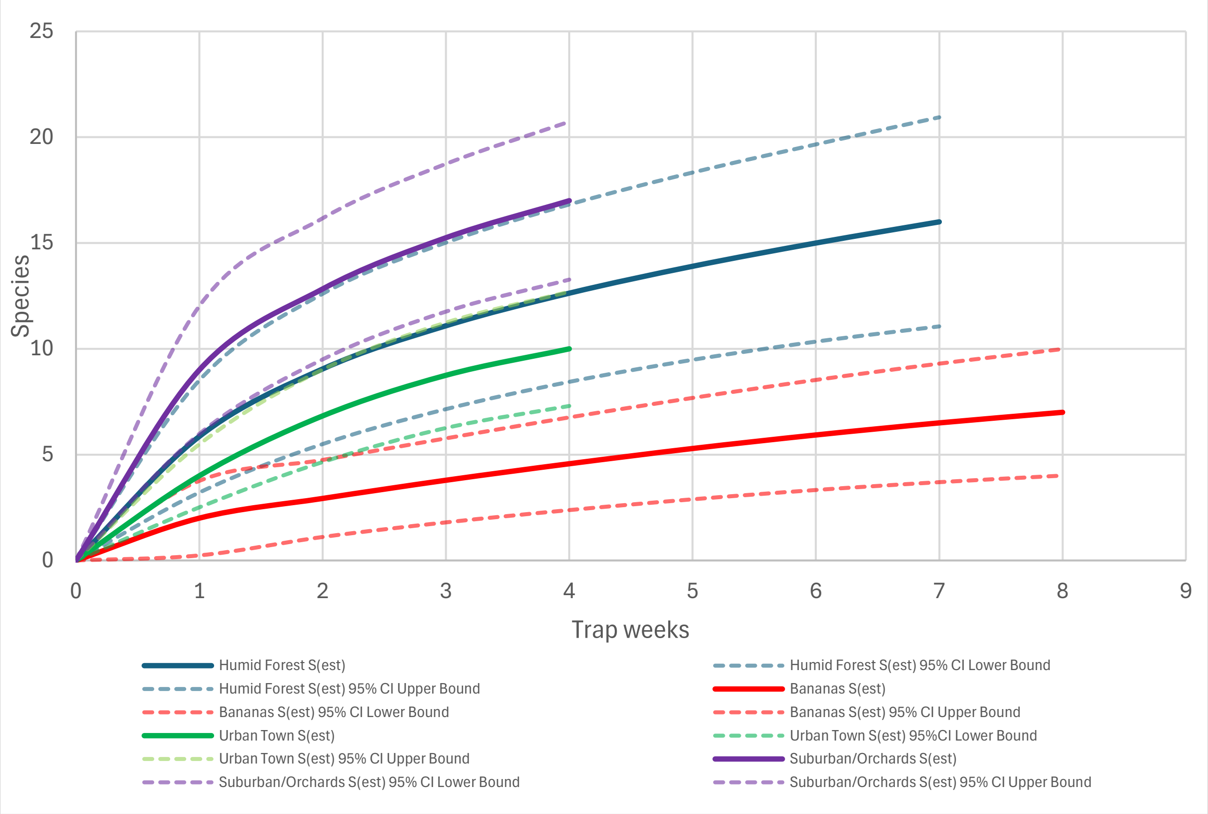
Accumulation of nymphalid butterflies species richness in the subtreatments.



When comparing species richness across all four ecosystem treatments, the suburban/orchard treatment showed a higher species accumulation compared to the humid forest (Figure 11). The urban town treatment displayed a similar accumulation pattern to the humid forest, with no significant difference in species richness. In contrast, the banana plantation treatment displayed a markedly lower accumulation curve.

Figure 11

Comparison of accumulation curves for all treatments, with confidence intervals



Chao Estimator

The Chao estimator provided insights into species richness across different treatments, revealing variations in biodiversity levels and sampling completeness (Table 6). The humid forest treatment recorded 16 observed species, but the Chao estimator suggested the inventory should contain 22 species, and therefore that the inventory was just 73% complete. In contrast, the banana plantation exhibited the lowest richness, with only seven observed species, a Chao estimate of 15 species, and therefore inventory completeness of 47%.

Table 6

Species richness and inventory completeness

Treatments	Species observed	Estimated richness (Chao)	95% CI	Chao SD	Inventory completeness (%)
Humid Forest	16	22	17-56	7	73
Bananas	7	15	8-69	11	47
Town	18	18	17-28	2	100
Suburban/Orchards	17	41	21-182	31	41
Urban	10	14	11-38	5	71

Note: SD = Standard deviation.

The town treatment, including both urban and suburban/orchard subtreatments, displayed an observed richness of 18 species, and a Chao estimate of 18 species, seemingly reaching 100% completeness. However, when analyzed separately, the suburban/orchards subtreatment presented 17 observed species, the Chao estimate suggested a potential richness of 41 species, and a low inventory completeness of 41%. This strong discrepancy highlights the need for further sampling. Conversely, the urban subtreatment recorded 10 observed species, with an estimated 14 species (Chao), and an inventory completeness of 71%, suggesting that while some species may still be undiscovered, the majority were accounted for within the sampling period.

Shannon Diversity Index and Dominance

The town treatment—which combines urban and suburban environments—recorded the highest Shannon index (2.60 ± 0.69). Suburban/orchard areas alone had a similarly high Shannon index of 2.46 ± 0.23, comparable to the humid forest (2.41 ± 0.20). In contrast, the banana plantation exhibited the lowest diversity index (1.40 ± 0.27). The urban town treatment showed intermediate values, with a Shannon index of 2.04 ± 0.65. These results are summarized in Table 7 but should be interpreted with caution because sampling effort differed among the treatments.

Table 7

Shannon diversity index per treatment

Treatment	Richness	Mean (richness)	±SD (richness)	Shannon	±SD (Shannon)
Banana plantation	7	2.0	0.50	1.40	0.27
Humid forest	16	5.9	1.25	2.41	0.20
Town	18	6.5	3.32	2.60	0.69
Urban town	10	4.0	2.12	2.04	0.65
Suburban/Orchards	17	9.0	2.24	2.46	0.23

Note. SD= Standard deviation.

The Shannon Index considers both species richness and dominance (related to abundance). The differences in dominance among species (and treatments) can be visualized by ordering species observed from most abundant to least abundant, and generating bar graphs to compare the relative abundances. The banana plantation, the least diverse ecosystem, displayed the highest dominance, with *Hermeuptychia hermybius* overwhelmingly abundant compared to the other species (Figure 12). This pattern highlights how disturbance and habitat modification can reduce richness while increasing dominance, leading to a more homogeneous butterfly community and less balanced ecosystem. The humid forest, one of the most diverse ecosystems, not only exhibited a higher number of species but also showed a more evenly distributed population, indicating lower dominance (Figure 13). While *Archaeoprepona amphimachus* was the most abundant species, other species had relatively similar representation, reflecting a balanced community structure. In contrast, the town ecosystem (both subtreatments combined) presented the highest level of richness among the treatments, but with slightly higher dominance compared to the humid forest (Figure 14). *Hermeuptychia hermybius* was the most abundant species, yet several others maintained notable presence.

The abundance patterns in the two subtreatments of the town revealed differences in species richness and dominance, likely influenced by habitat usage and vegetation. The urban town exhibited lower species richness and higher dominance, with *Hermeuptychia hermybius* being notably more abundant than the other species, similar to the results from the banana plantation (Figure 15). In contrast, the suburban/orchards ecosystem displayed higher richness, with a broader distribution of species and lower dominance, as several species such *as Hermeuptychia hermybius, Historis acheronta,* and *Opsiphanes fabricii* had relatively similar abundances (Figure 16).

Figure 12

Dominance of nymphalid butterfly species for the banana plantation

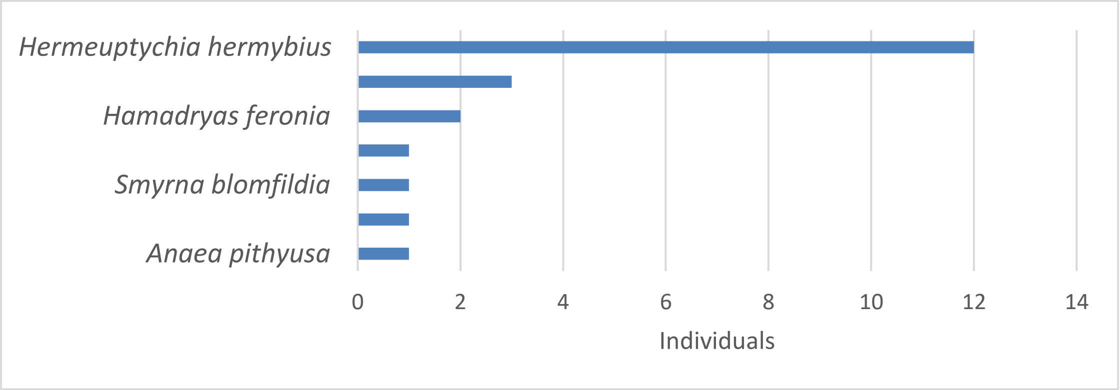


Figure 13

Dominance of nymphalid butterfly species for the humid forest

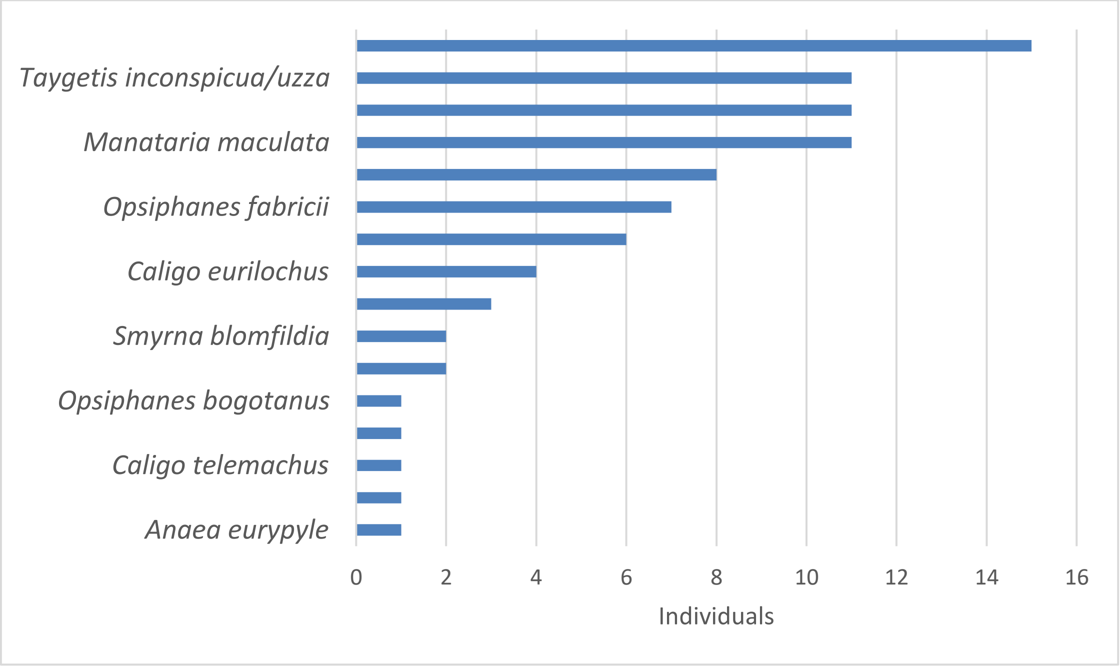


Figure 14

Dominance of nymphalid butterfly species for the town

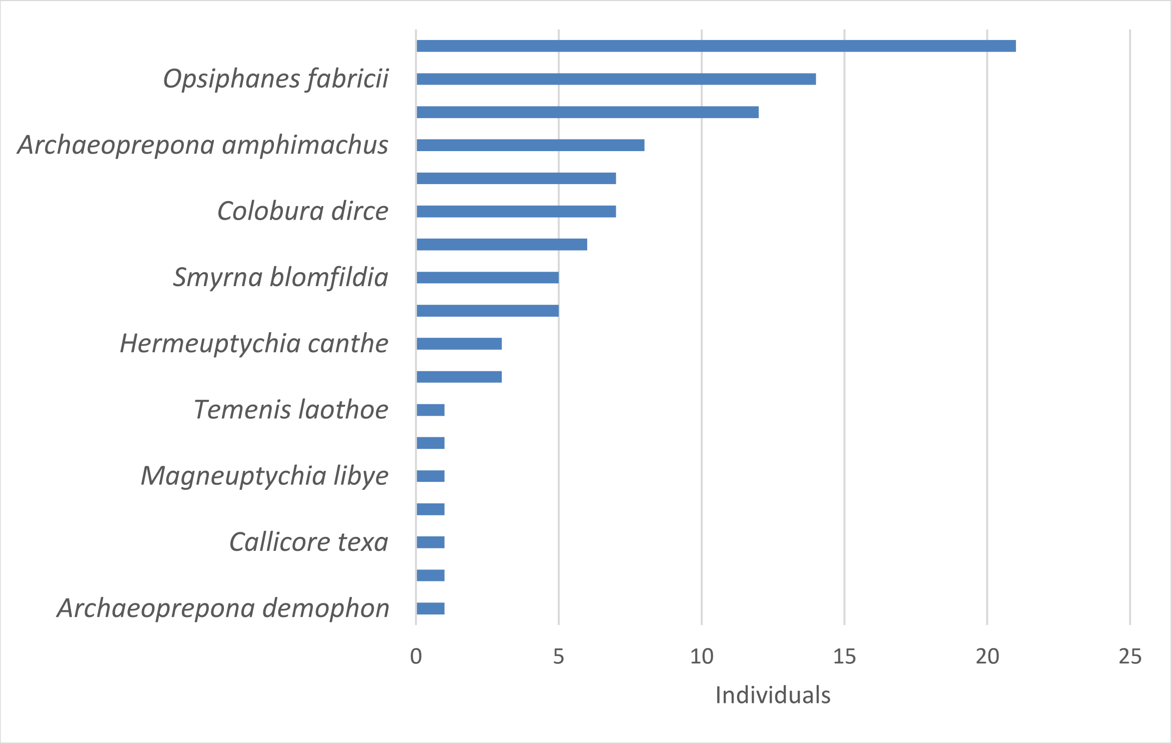


Figure 15

Dominance of nymphalid butterfly species for the urban subtreatment

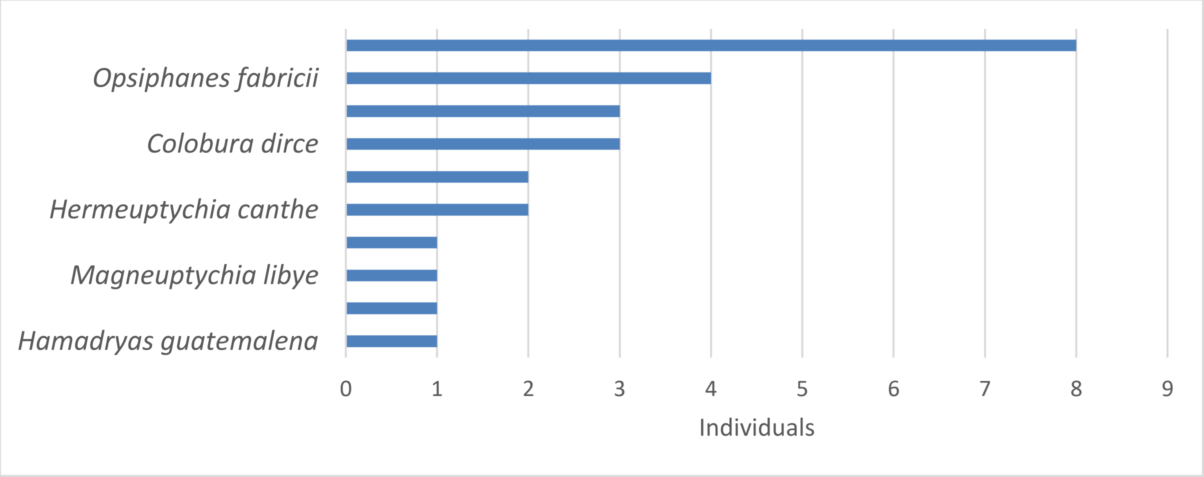
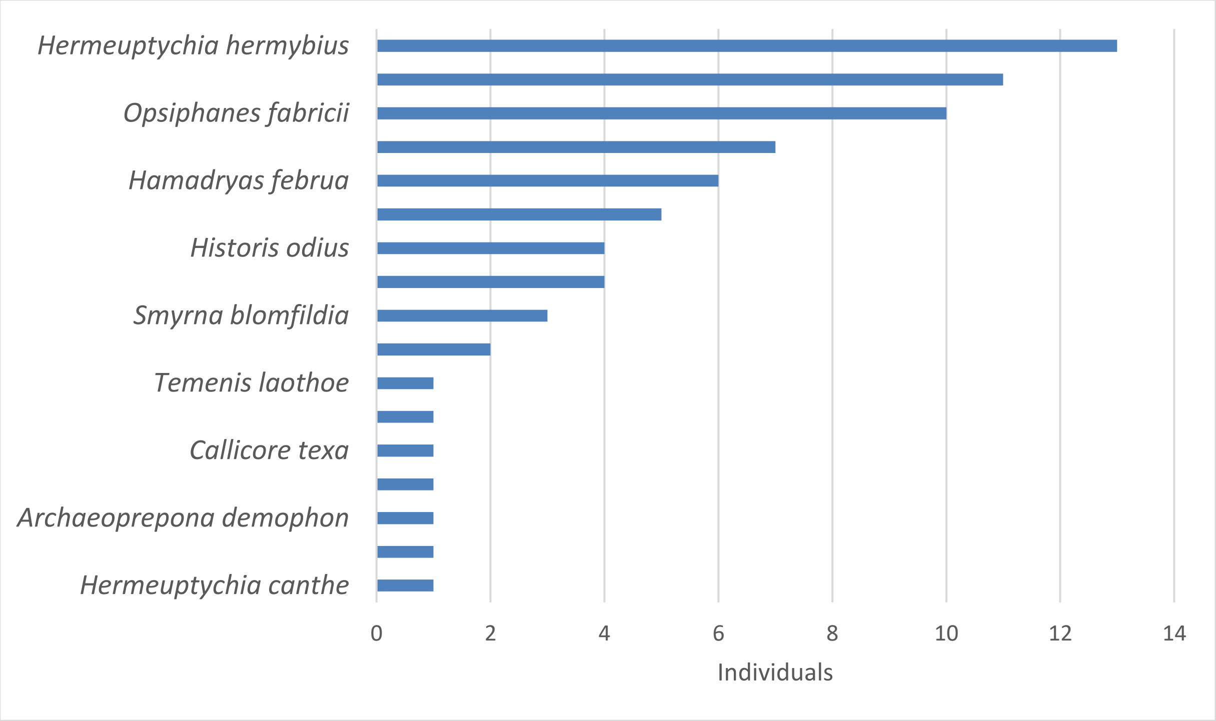


Figure 1166

Dominance of nymphalid butterfly species for the suburban/orchards subtreatment



Ecosystem Effect on Species Richness

Analyzing richness across ecosystems demonstrated highly significant differences across the treatments (*F* = 12.712, *p* = <0.001) (Table 8). This confirms that species richness is not uniform among ecosystems, with more conserved environments like humid forests and suburban areas displaying higher richness than intensely intervened areas such as banana plantations. As shown in Table 8, the notable variation supports the hypothesis that habitat transformation reduces the richness of species in an ecosystem.

Table 8

Results of ANOVA tests

Variable	Treatment	Sum of Squares	df	Mean Square	*F*	*p*
Richness	Ecosystem	136.33	3	45.444	12.712	< .001
Shannon	Ecosystem	5.727	3	1.909	7.518	0.001
Individuals	Trap type	285.02	2	142.51	3.472	0.051
Individuals, with Brown-Forsythe correction	Trap type	285.02	2	142.51	4.715	0.021
Richness	Trap type	34.268	2	17.134	2.14	0.144
Richness, with Brown-Forsythe correction	Trap type	34.268	2	17.134	2.766	0.087

There were clear differences in richness across treatments, measured as the mean number of species captured per trap (Table 7). The banana plantation had the lowest richness, with an average of only 2.0 species per trap (±0.50). In comparison, the humid forest showed nearly a threefold increase, with a mean richness of 5.9 species per trap (±1.25). Even higher values were observed in the suburban/orchard areas, which reached 9.0 species per trap (±2.24), more than four times higher than the banana plantation. Urban towns showed intermediate richness (4.0 ± 2.12), while the combined town treatment (urban + suburban) averaged 6.5 species per trap (±3.32), likely reflecting the increased variability from mixing two habitat types.

The analysis of the Shannon diversity index by treatment also shows clear significant differences across ecosystem types (Table 8). Thus, conserved habitats not only harbor more species but also maintain a more balanced community structure, while anthropogenically altered areas like banana crops tend to be dominated by a few highly tolerant species, thus decreasing their Shannon index.

The banana plantation had the lowest Shannon index (1.40 ± 0.27), indicating not only fewer species but also more dominance. In contrast, the town treatment (urban + suburban) showed the highest diversity (2.60 ± 0.69), suggesting a more even distribution of individuals among a greater number of species. Suburban/orchard areas (2.46 ± 0.23) and the humid forest (2.41 ± 0.20) followed closely, both with high diversity values. Urban town presented intermediate diversity (2.04 ± 0.65), higher than the banana plantation.

Trap Type Effect on Sampling

The ANOVA results for the number of individuals revealed a statistically significant difference between trap types when adjusting for variance heterogeneity using the Brown-Forsythe correction ($F = 4.715$, $p = 0.021$) (Table 8). The uncorrected model approached significance as well ($p = 0.051$), suggesting that the type of trap significantly influenced the number of butterflies captured. Large traps captured considerably more individuals (mean = 12.46) compared to small traps (mean = 5.67) and cube traps (mean = 5.17) (Table 9).

Table 9

Mean abundance and richness based on traps

Trap	Mean (abundance)	±SD (abundance)	Mean (richness)	±SD (richness)	N
Cube	5.167	4.792	3.333	2.160	6
Large	12.455	7.980	6.000	3.435	11
Small	5.667	3.724	3.833	1.941	6

Note: SD = Standard deviation.

An analysis of species richness across different trap types revealed no statistically significant differences, even when using the Brown-Forsythe correction ($F = 2.766$, $p = 0.087$) (Table 8). The results suggest that the differences in richness and diversity among treatments are reliable and not due to variations in trap size, meaning the patterns observed reflect real differences in butterfly communities.

Species Indicators of Ecosystem Health

A total of 29 species were recorded (Appendix A), with 204 butterflies from the Nymphalidae family captured across three habitat types (Table 10). Only one species, *Opsiphanes fabricii*, was found in all ecosystems, suggesting a high degree of adaptability. Conversely, species found mostly in the humid forest were proposed as indicators of a healthy habitat, as they are likely more sensitive to ecosystem disturbances. These species include *Archaeoprepona demophon, Manataria maculata,* *Morpho helenor*, and *Taygetis sp*. The most abundant species, found almost exclusively in highly disturbed habitats, was *Hermeuptychia hermybius*, which is therefore proposed as a degraded habitat indicator.

Table 10

Species recorded in each treatment

Species	Humid Forest	Suburban/Orchards	Urban	Town	Bananas
Anaea eurypyle	1				
Anaea pithyusa					1
Archaeoprepona amphimachus	13	7	1	8	
Archaeoprepona demophon	6	1		1	
Archaeoprepona demophoon	1	1		1	
Caligo eurilochus	4				
Caligo telemachus	1				
Callicore texa		1		1	
Colobura dirce	8	4	3	7	
Eunica tatila		1		1	
Hamadryas februa		6		6	
Hamadryas feronia		5		5	2
Hamadryas guatemalena		2	1	3	
Hermeuptychia canthe		1	2	3	
Hermeuptychia hermybius		13	8	21	12
Historis acheronta	3	11	1	12	
Historis odius		4	3	7	1
Magneuptychia libye			1	1	
Manataria maculata	11				
Morpho helenor	11				
Myscelia cyaniris		1		1	
Napeogenes tolosa	1				
Opsiphanes bogotanus	1				
Opsiphanes fabricii	7	10	4	14	3
Pareuptychia metaleuca	2				
Smyrna blomfildia	2	3	2	5	1
Taygetis inconspicua/uzza	11				1
Temenis laothoe		1		1	
Abundance	83	72	26	98	21

Discussion

Overall, these results indicate that less disturbed environments, such as humid forests and suburban/orchard areas, support higher species richness and diversity. However, urban areas with vegetation can still maintain some level of butterfly biodiversity. In contrast, the banana plantation demonstrated significantly lower richness and diversity.

The lowest biodiversity was observed in the most intensively managed treatment, which aligns with expectations for monoculture systems, where habitat homogeneity and frequent intervention limit species richness (Tscharntke et al., 2005). In contrast, the relatively high diversity observed in the suburban/orchard treatment could be linked to the feeding habits of the Nymphalidae family, which primarily consumes rotten fruit—an abundant resource in these environments. The town treatment (urban + suburban) displayed the highest species diversity, likely due to the vegetation variability and perhaps intermediate disturbance levels of, which are often correlated with higher biodiversity (Fox, 1979).

The completeness of the butterfly inventory varied across treatments, influenced by methodological limitations. According to the ANOVA for the number of individuals captured, large traps collected significantly more butterflies than both small and cube-shaped traps (Table 9). As a result, treatments where less effective traps were used more frequently—such as the humid forest, which relied more heavily on small traps—may have lower inventory completeness. This could have led to an underestimation of species richness in those areas. However, when analyzing the Shannon diversity index, trap type did not show a statistically significant effect, indicating that while the total number of individuals may have varied by trap design, overall diversity remained consistent across trap types (Appendix B). This suggests that trap type did not bias the representation of butterfly communities. The humid forest may have had a slight underestimation in species richness, but the lack of a complete inventory there can be attributed to incomplete sampling, and the challenge of detecting rare species in complex habitats.

Low species diversity could be linked to unmeasured stressors. In the banana plantation, factors such as pesticide use and habitat simplification likely contributed to lower butterfly diversity in this environment (Potts et al., 2010). These variables were not measured in the present study, but future research should consider assessing them directly. In the humid forest, local disturbances like cacao harvesting and an eco-trail may have altered forest's structure and microclimate. These changes could have reduce the availability of host plants or increased edge effects (Dumbrell y Hill, 2005). Consequently, the "El Carmen bird sanctuary" may not have accurately represented of a healthy forest, which limited the species detected as indicators of a healthy ecosystem.

Temporal and procedural constraints also limited the quality of the data. The short sampling period likely contributed to incomplete sampling (Colwell y Coddington, 1994). Extending the duration of sampling would improve richness estimates and help detect rare species. Additionally, inconsistent bait application—due to inexperience—could have caused variable capture rates, a known issue when protocols are not fully standardized (Henry et al., 2015).

In the town treatment, both subtreatments (urban and suburban) had the same number of traps, yet the suburban inventory was considerably less complete than the urban one. The urban environment likely harbored fewer undetected species, offering a more accurate picture of its butterfly community. In contrast, the suburban area may have had greater diversity that was not fully captured.

Conclusions

Butterfly richness varied significantly across the four ecosystems. The suburban/orchard areas showed the highest species richness, followed by the humid forest and the urban town. In contrast, the banana plantation exhibited the lowest richness, accounting for only 25% of the total species pool recorded in the study. Notably, butterfly richness showed a decline of 56% in the banana plantation compared to the humid forest. The suburban and urban treatments combined represented 64% of all observed species, with the suburban/orchard area alone capturing 60%, and the humid forest 57%. These results highlight the sharp differences in ecological quality between the ecosystems and reinforce the idea that certain human-modified landscapes, particularly those with mixed vegetation or fruit availability, can sustain high butterfly richness, especially Nymphalid butterflies.

Across biodiversity indices and accumulation curves, the banana plantation consistently showed the lowest diversity and most homogeneous community, even when compared to urban environments. Interestingly, even the humid forest failed to reach the suburban/orchard area's high richness levels. This pattern does not appear to be solely related to vegetation cover, as the banana plantation is also surrounded by vegetation but still presents low diversity. These findings suggest that intensive agricultural practices such as pesticide use, monoculture planting, and the simplification of habitat structure may exert a more detrimental effect on butterfly communities than urbanization under certain conditions.

Several Nymphalid butterflies emerged as potential bioindicators of habitat quality. Four species demonstrated a notably stronger association with high-quality, less-disturbed habitats. On the other hand, one species (*Hermeuptychia hermybius*) was predominantly found in disturbed environments and may serve as an indicator of degraded conditions. These putative indicator species highlight the ecological value of Nymphalid butterflies for monitoring environmental health, particularly within tropical agricultural systems, where rapid assessments are needed to guide sustainability and conservation efforts.

Recommendations

Some bias in the comparisons across treatments can be removed by using homogeneous and efficient traps throughout the study. Since large and cube-shaped traps demonstrated higher effectiveness in capturing butterflies, future research should prioritize their use over small traps. Standardizing trap selection across treatments would not only enhance data comparability but also increase the likelihood of recording a more complete inventory of species present in each habitat.

Increasing the sampling duration is recommended to enhance the completeness of the species inventory. A longer sampling period would allow for more robust species accumulation curves and a better understanding of seasonal variations in butterfly populations.

Expanding the study to a wider range of environments would also yield valuable insights. Future research should include additional urban areas with varying degrees of disturbance, organic plantations and conventional fruit plantations, and primary forests to improve the determination of indicator species. Comparing butterfly biodiversity could help highlight the impacts of land use and anthropogenic intervention on ecosystem health.

Another aspect to consider for further research is the potential impact of pesticides on butterfly populations. Since banana plantations are known for their pesticide use, laboratory analyses could be conducted to assess the presence of pesticide residues in butterflies collected from these areas. Understanding how pesticides influence butterfly health and survival would be beneficial for both conservation efforts and sustainable agricultural practices.

By implementing these methodological improvements and expanding the scope of future research, more comprehensive insights can be gained into how habitat disturbances and management practices influence butterfly diversity. These recommendations will help refine conservation strategies and contribute to a deeper understanding of species distribution across different landscapes.

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Appendix

Appendix A

Visual catalogue of Nymphalid butterfly species found

Anaea eurypyle

Anaea pithyusa

Archaeoprepona amphimachus

Archaeoprepona demophon

Archaeoprepona demophoon

Caligo eurilochus/telemachus

Callicore texa

Colobura dirce

Eunica tatila

Hamadryas februa

Hamadryas feronia

Hamadryas guatemalena

Hermeuptychia canthe

Hermeuptychia hermybius

Historis acheronta

Historis odius

Magneuptychia libye

Manataria maculata

Morpho helenor

Myscelia cyaniris

Napeogenes tolosa

Opsiphanes bogotanus

Opsiphanes fabricii

Pareuptychia metaleuca

Smyrna blomfildia

Taygetis inconspicua/uzza

Temenis laothoe

Appendix B

Shannon index, individuals and richness per trap per ecosystem for nymphalid butterflies

Traps	Treatment	Richness	Individuals	Shannon	Trap type
1	Humid forest	4	5	1.33	Small
2	Humid forest	5	8	1.56	Small
3	Humid forest	7	12	1.86	Small
4	Humid forest	6	21	1.61	Large
5	Humid forest	8	19	1.91	Large
6	Humid forest	6	9	1.74	Large
7	Humid forest	5	9	1.43	Large
1	Bananas	2	2	0.69	Cube
2	Bananas	2	3	0.64	Cube
3	Bananas	2	3	0.64	Large
4	Bananas	1	2	0.00	Large
5	Bananas	2	2	0.69	Large
6	Bananas	2	2	0.69	Small
7	Bananas	2	3	0.64	Small
8	Bananas	3	4	1.04	Small
1	Urban	6	7	1.75	Cube
2	Urban	6	14	1.35	Cube
3	Urban	1	1	0.00	Cube
4	Urban	3	4	1.04	Cube
5	Suburban	6	13	1.67	Large
6	Suburban	12	24	2.30	Large
7	Suburban	8	16	1.96	Large
8	Suburban	10	19	2.08	Large