Journal of Colombo Geographer

An Assessment of Species Diversity and Temporal Variation of Butterflies in Pinnawala Open Air Butterfly Park, Sri Lanka

M.T.F. Nifla[1] and Punniyarajah Kirishanthan[2]

[1&2] *Department of Geography, University of Colombo, Colombo*

Abstract

Butterflies (Lepidoptera) contribute to maintaining the health and diversity of ecosystems. Sri Lanka has nearly 248 species of butterflies, including 31 endemic species, and has established a series of conservation schemes, such as the Pinnawala Open-Air Butterfly Park, giving butterfly conservation an ex-situ environment. This study assessed butterfly species diversity and temporal variation in the park through comparison of species release reports by park management for 2019, 2022, and 2023 (no data between 2020-2021 because of the COVID-19 pandemic). The data were supplemented through direct observation in the field and key informant interviews. Species diversity indices such as Shannon Diversity Index (H), Shannon Equitability Index (EH), Simpson Diversity Index (D), and Gini Simpson Index (G)—were calculated, and thematic analysis was conducted based on interview data. 7,388 individuals belonging to 20 species across four families (Papilionidae, Pieridae, Nymphalidae, and Lycaenidae) were tallied, of which Nymphalidae was the most species-rich. Evenness (EH = 0.85) and diversity (H = 2.34; D = 0.11) were highest in 2019, and richness was highest in 2023 (S = 20). The monthly trends indicated the lowest diversity in February and November, and the highest diversity in April, June and December. Season peak occurrence was correlated to mid-year environmental trends and effective management of the gardens, such as limiting temperature range variation as well as abundant nectar, water, and host plant supplies. It stresses the critical feature of routine upkeep in the parks towards the continued butterfly diversity. The enhancement of conservation and culture, as well as the introduction of new species on top of their rightful host vegetation, is recommended towards the optimization of the extent of ex-situ sites such as the Pinnawala Open-Air Butterfly Park towards enhanced biodiversity.

Keywords: Butterfly, Conservation, Open-Air Butterfly Park, Species diversity, Temporal distribution

1. Introduction

Butterflies play an important role in keeping the ecosystem healthy and promoting biodiversity as primary pollinators. Numerous plant species would fail to reproduce without the services of butterflies and other pollinators, which result in loss of food plants and habitats for other organisms. Their colourful appearances, shapes, and elegant flight provide beauty value and have been used as a symbol of grace and beauty since the 18th century (Manzoor.F et al, 2013).

Corresponding author.
E-mail address: niflathaha00@gmail.com (M.T.F. Nifla)

Butterflies and moths, together with their close family members, the caddisflies, evolved from a common ancestor around 200 million years ago when the landmasses of Earth were very different from what they are today. The five big butterfly families are Hesperiidae, Lycaenidae, Nymphalidae, Papilionidae, and Pieridae, which have been identified worldwide (Poorten.N, Poorten G.M, 2016). Despite its small size, Sri Lanka's diverse topography, climate, and vegetation provide a rich butterfly fauna (Lepidoptera) of 247 species, including 31 endemics and 84 endemic subspecies (Poorten.N, Poorten G.M, 2016; Mathew, 2016; Perera & Bambaradeniya, 2006; Smetacek, 2002; Elanchezhyan et al., 2017).

Butterfly populations are influenced by many environmental factors. They require sunlight for survival (Thakur et al., 2017), and nectar during rainy seasons boosts their population (Weerakoon & Ranawana, 2021). Plant diversity, particularly native plant diversity, plays an important role in the distribution of butterflies (Silva et al., 2021; Subedi et al., 2021). However, habitat loss due to deforestation, urbanization, and the use of agrochemicals, specifically pesticides, led to a significant decline in Sri Lankan butterflies (Samarasinghe.M.D.P. et al, 1998; Jayaneththi, 2020; Parandhaman et al., 2012). As a response to this, both in-situ (within their natural habitats) and ex-situ (within controlled environments such as zoos and parks) conservation methods are being adopted (Sanwal.C.H.et al, 2017). The Sri Lankan Dehiwala Zoo started operations in 1936, and due to the available space, Sri Lanka's first open-air zoo, the Pinnawala Open Air Zoo, was opened in 2015 (Department of National Zoological Gardens, 2023). This half-controlled environment is an interesting option to see and conserve butterfly species. Butterflies are environmentally and climatically sensitive, and therefore are effective bioindicators (Manzoor.F et al, 2013).

Nevertheless, although there have been several studies on the diversity of butterflies in natural ecosystems, there have been few studies on butterfly populations in ex-situ settings such as the Pinnawala Butterfly Open Air Park. In addition, there have been few studies that have examined temporal changes in butterfly diversity based on multiple measures of biodiversity. This research fulfils this gap by performing an in-depth assessment of butterfly species diversity in a semi-natural setting, contributing new information towards conservation biogeography in Sri Lanka (Thakur et al., 2017). This study attempts to close the research gap concerning bio-geographical assessments of butterfly species diversity in the Pinnawala Butterfly Open Air Park. In particular, it responds to two key research agendas:

1. To assess the species diversity of butterflies in the park.

2. To compare the temporal changes of butterfly diversity annually and monthly.

Through exploring these aspects, the study enhances our understanding of how populations of butterflies respond to semi-controlled conditions and provides further input towards more efficient conservation processes to mitigate the decrease of species in Sri Lanka.

2. Materials and Methods

2.1 Background of the Pinnawala Open Zoo, Sri Lanka

Pinnawala Open Zoo is a zoological garden in Sri Lanka, situated close to the Pinnawala Elephant Orphanage. The butterfly park is one of the parts of the zoo. It is 13 km from Kegalle City and 2 km from Pinnawala Elephant Orphanage (Bernard Tours, 2020). Pinnawala Butterfly Park is located between 7° 17'48.5″ northern latitudes and 80° 23'13.4" eastern longitudes.

Since its launch in late 2018, the open-air butterfly park has been managed by four caretakers dedicated to conserving the park. Their primary responsibilities are tracking and preserving butterfly populations, handling plant life in the park, and creation of habitats for butterflies. Some of their particular responsibilities include the maintenance of butterflies when they are in the egg and pupa stages, creation of proper environments, and tracking and recording butterfly behaviour. In addition, visual monitoring is done every hour during the day from 8 am to 4 pm.

Figure 1 illustrates the key features of the Pinnawala Butterfly Open Air Park, highlighting various zones critical to butterfly conservation and research. The park includes a small pond (D) and a lake complete with a waterfall (E) that serves as a focal point of the landscape. Adjacent to the water bodies, there is a designated hut area (E) providing shelter for visitors. Flanking these features are areas planted with flowering species (F), serving as habitats for butterflies. The butterfly living area is specifically designed to support their natural behaviours and lifecycle. In addition, the park houses a net enclosure (net house) (I) for controlled observation of butterfly activity. Key research facilities, including a dedicated butterfly laboratory and an inspection office(H), are also strategically positioned to facilitate ongoing scientific study.

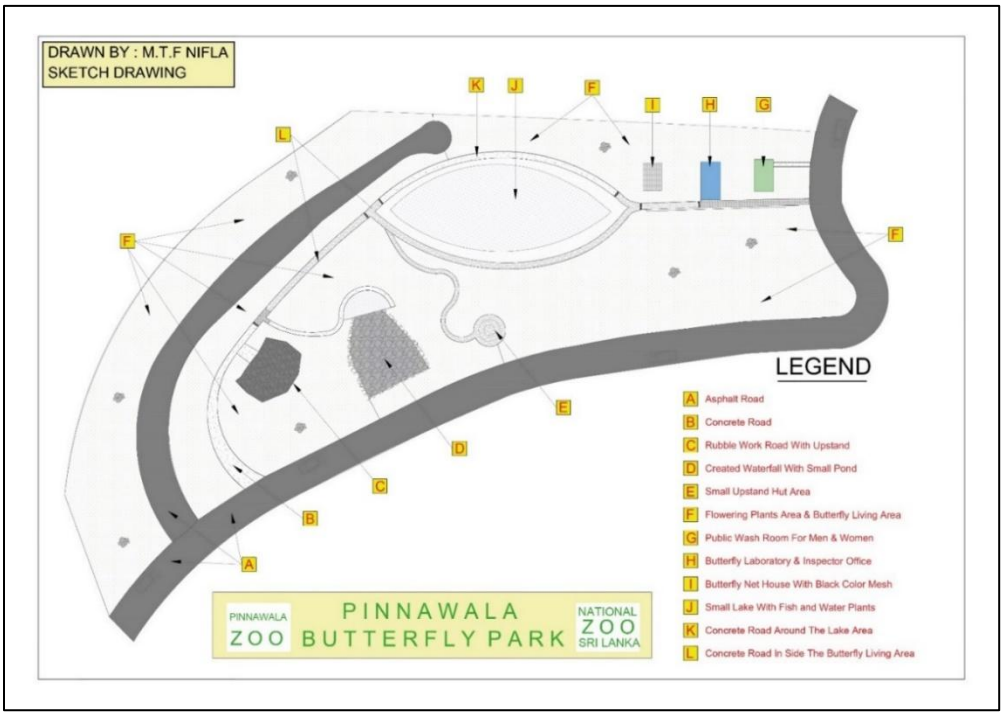

Figure 1: Pinnawala Butterfly Park Sketch Map

Source: Drown by Author 2024

2.2 Data

This study primarily relies on secondary data from the Pinnawala Butterfly Park Management Committee. Due to the suspension of zoo operations and monitoring during 2020 and 2021 because of the COVID-19 pandemic, continuous records from are unavailable for this period. Data collection resumed in 2022 and 2023, coinciding with the park's recovery and operational reactivation following its inaugural year in 2019.

The dataset comprises monthly records of butterfly counts, categorized by families and species, for the years 2019, 2022, and 2023. In data analysis, several indices will be employed to evaluate butterfly diversity comprehensively.

2.2.1 Primary Data Collection

The study's primary data were gathered from two main sources: key informant interviews and direct field observations. These methods were essential in gathering contextual data alongside numerical species data and helped to

understand the practical dynamics of butterfly conservation within the park more profoundly.

Key informant interviews were one of the primary data collection methods employed in this research. The approach provided in-depth information on various aspects of the butterfly park, contributing immensely to the research objectives.

The individuals interviewed were:

Chief Manager

2 Development Officers

4 Caretakers

Observations focused on butterfly species presence, abundance, and habitat use, while interviews provided contextual insight into park operations and conservation practices.

04.11.2023
Discussion with the Chief Manager of Pinnawala Butterfly Park on the research proposal; observations of the study area and butterflies.
13.01.2024
Interviews were conducted with caregivers. Observations were made of the study area, as well as the flora and fauna present.
14.01.2024
Discussion with development officers; observations of the study area, flora, fauna, and caretaker activities.
04.02.2024
A key informant interview was conducted with the Chief Manager. Butterfly data for 2019 and a flora list of the park were obtained.
17.02.2024
Butterfly data for 2022 and 2023, along with a map of Pinnawala Zoo, were obtained.
01.06.2024
Discussed analysis results with park management; observed butterfly structure diagram.

These interviews provided valuable context and information beyond what was observable, helping to better understand the factors influencing the presence of butterflies and their habitat within the park. Microsoft Excel 2013 software was used for graphical representations.

In data analysis, several indices will be employed to evaluate butterfly diversity comprehensively.

To evaluate butterfly species diversity,

Shannon diversity index formula

$H=-\sum(Pi)\times LN(Pi)$

Where

H= Shannon diversity index,

Pi= Proportional abundance of the species

$\sum$ = Sum Symbol

value of the Shannon diversity index detected by the Shannon Index typically ranges between 0 and 3.5, with higher values indicating greater biodiversity (Supriatna, 2018; Libre Texts Statistics, 2024).

Low diversity: When ($H < 1.5$), it indicates low biodiversity.

Medium diversity: When (1.5 -2.5), the ecosystem has medium biodiversity.

High diversity: Values greater than 2.5 indicate high biodiversity ($H > 2.5$).

In further analysis, a trend line at ($H = 1.5$) is used as a boundary to differentiate low from higher diversity levels in charts, serving as a reference point for researchers. This boundary helps visualize and analyse shifts in biodiversity.

Shannon Equitability Index formula

$EH=H / LN(s)$

Where,

H= Shannon diversity index

LN(S)=Natural logarithm of the total number of species in the habitat

Simpon^' s diversity index formula

$D=\sum (ni\ (ni-1) \div (N(N-1)$

Were,

D = Simpson Index

ni = Number of individuals of all species

N = total number of individuals in the species

The value of the Simpson index ranges from 0-1, with 0 representing infinite diversity and 1 representing no diversity, so the larger the value of D, the lower the diversity. Here, the author uses two biodiversity indices to compare the following results.

Gini-Simpson diversity index formula

G=(1-D)

D = Simpson Index

Evenness is calculated by Shannon Equitability Index and Gini-Simpson Index. If the species abundance is completely equal proportion, evenness would be equal to 1. Microsoft Excel was used to carry out the statistical analysis and prepare graphs.

These indices were selected to provide a general evaluation of species diversity, richness (the number of species), and evenness (the way individuals are distributed). Shannon and Simpson indices were used simultaneously to cross-validate diversity trends and confirm the outcome reliability. All procedures were done in Microsoft Excel 2013.

3. Results and Analysis

3.1 Butterfly Species in the Park

This section provides information regarding butterfly species released at the Pinnawala Butterfly Park during the three years 2019, 2022, and 2023. Figures of butterflies were observed in the park.

Table 4.1 provides data on butterfly species that were released into the park from 2019 to 2023.

Table 1: Butterfly Species Visited in the Park

family		Scientific Name	Common Name	IUCN Status	Frequency Status
Papilionidea	1	*Papilio poymnestor parinda*	Common Mormon	LC	C
	2	*Pachliopta hector*	Crimson Rose	LC	C
	3	*Pachliopta aristolochiae ceyolica*	Common Rose	LC	C
	4	*Graphium agamemnon menides*	Tailed Jay/ Green Jay	LC	O
	5	*Chilasa clytia lankeswara*	Common Mime	LC	O
	6	*Papilio polymnestor parimda*	Blue Mormon	LC	O
	7	*Papilio demoleus demoleus*	Lime Butterfly	LC	O
	8	*Thorides darsius*	Common / Ceylon Bird wing	LC	R
	9	*Graphium sarpedon*	blue Bottle	LC	R
Nymphalidea	10	*Euploea Klugii sinhala*	Common Crow/ Indian Crow	LC	C
	11	*Elymnias hypermnestra fraterna*	Common Plam Fly	LC	O
	12	*Tirumala septentrionis musikanos*	Blue Tiger	LC	C
	13	*Phalanta phalantha*	Common Leopard	LC	O
	14	*Danaus chrysippus*	Plain Tiger	LC	C
	15	*Parantica aglea*	Glassy Tiger	LC	O
	16	*Junonia almana almana*	Peacock Pancy	LC	R
Pieridae	17	*Catosilia pomona*	Lemon Emigrant	LC	C

	18	*Eurema hecabe simulata*	Common Grass Yellow	LC	C
Lyceanidae	19	*Talicada nyseus nyseus*	Red Pierrot	LC	R
	20	*Chilades pandava lanka*	Plains Cupid	LC	R

LC = Least Concern, C = Common, O = Occasional, R= Rare

Source: Prepared by Authors based on 2109, 2022, and 2023 data obtained from Pinnavala Open Zoo.

All butterfly species recorded in the park are categorized as "Least Concern" (LC) according to the IUCN Red List. In the study, 40% of the total butterfly species observed at the site were identified as common (C), 35% were identified as occasional (O), and 25% were classified as Rare (R) based on their visitation patterns (Table 1).

3.2 Species Diversity of Butterflies in the Park

The diversity of butterfly species has been examined from three different perspectives: annually, monthly, and by individual species.

According to observations recorded by the researcher, along with the species provided by the secondary data of the Pinnawala Butterfly Park Management Committee, some butterfly species were found through the researcher's direct field observation that were not discussed by prior records. species (Common Tiger, Common Five-ring, Small Branded Swift, and Cabbage White) were identified apart from those listed by the Park Management Committee. These species may be new or occasional emigrants to the park in 2024, potentially reflecting recent habitat shifts or seasonal incidences of migration. Photographic evidence of these other species is shown in Figures 1-4. These observations in the field supplement the secondary data and present a more contemporary image of butterfly diversity in the park.

Table 2: Butterfly Species Released in the Park

	Common Name	**2019**	**2022**	**2023**	**N**
		n	**n**	**n**	
1	Common Mormon	247	60	216	523
2	Crimson Rose	205	195	33	433
3	Common Rose	200	110	39	349
4	Tailed Jay/ Green Jay	18	3	7	28
5	Common Mime	7	19	16	42
6	Blue Mormon	14	0	19	33
7	Lime Butterfly	336	0	12	348
8	Common / Ceylon Birdwing	*	*	8	8
9	Blue Bottle	*	*	6	6
10	Common Crow/ Indian Crow	204	28	57	289
11	Common Plam Fly	6	0	0	6
12	Blue Tiger	563	85	378	1026
13	Common Leopard	113	15	2	130
14	Plain Tiger	389	3	103	495
15	Glassy Tiger	63	19	38	120
16	Peacock Pancy	*	*	31	31
17	Lemon Emigrant	315	334	513	1162
18	Common Grass Yellow	335	822	1149	2306
19	Red Pierrot	3	19	5	27
20	Plains Cupid	*	*	26	26
		3018	**1712**	**2658**	**7388**

n=Number of individuals released N=Total number of individuals released *= The species is not found in the park, 0= The species is not found in in particular year

Source: Prepared by Authors based on 2109, 2022, and 2023 data obtained from Pinnawala Open Zoo

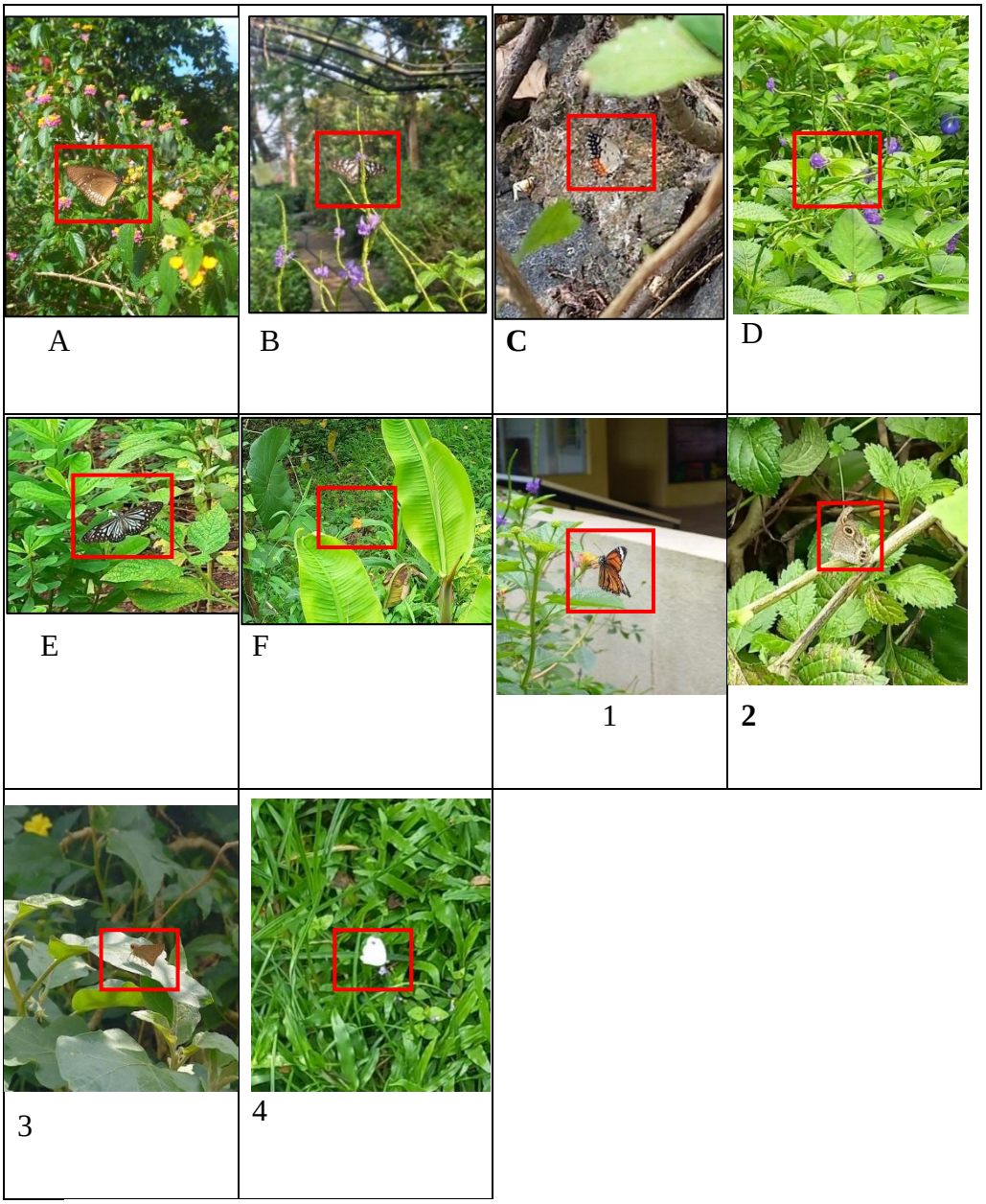

Figure A-F: The observed butterfly species in the park & Figure 1-4: Butterfly species identified beyond the Park Management Committee list

A =Common Indian Crow, B= Blue Tiger, C=Red Pierrot, D=Lemon Emigrant, E= Glassy Tiger, F= Plain Tiger 1= Common Tiger - Danaus genutia 2 = Common Five-ring - Ypthima baladus, 3 = Small Branded Swift - Pelopidas mathias, 4 = Cabbage White - Pieris Rapae

Source: Field Observation 2024

Table 2 illustrates the biodiversity analysis of the butterfly species observed in the park over three years. The analysis was done on the total number of species released across all three years (2019,2022 and 2023). A total of 7,388 individuals, representing 20 species from four families, were released into the park during 2019, 2022, and 2023.

The year 2019 indicated the highest number of butterflies released, whereas 2022 had the fewest. From 2019 to 2022, the butterfly population in the park decreased by 1,306 individuals. In 2023, 946 individuals were released, indicating an increase compared to 2022. Based on the data of butterflies observed and released during the three years, the species richness remains at 20(Table 4.1 for species-related data).

Among the 20 species released into the park, the Common Grass Yellow (n=2,306) was the most abundant, followed by the Lemon Emigrant (n=1,163) and the Blue Tiger (n=1,026). The Common Grass Yellow and Lemon Emigrant were the primary species released in 2023, while the Blue Tiger had the highest release in 2019. Of note, several species (Blue Mormon, Lime Butterfly, and Common Plam Fly) did not return to the park after 2019, while others appeared only in 2023. The least common species released across all three years were the Red Pierrot (n=27) and Tailed Jay (n=28). Other species, such as the Blue Mormon (n=33) and Common Mime (n=42), were also found in limited numbers. Red Pierrot and Common Mime were released in 2022, while Tailed Jay was released in 2019. The Blue Mormon was not recorded in 2022. Aside from these, the majority of the species had their largest release in 2019.

3.2.1 Individual species diversity in the park

The diversity of all 20 species documented within the park falls under the low diversity category in the Shannon index ($H < 1.5$). This indicates limited species richness and evenness in the park's butterfly population.

Notably, four species, Ceylon Bird Wing, Blue Bottle, Common Palm Fly, and Peacock Pansy, exhibited a diversity index of $H = 0$ & $D = 1$, showing no significant diversity or dominance in their presence. The Lemon Emigrant was identified as the species with a high equilibrium in distribution, achieving a Shannon Equitability Index (EH) of 0.90. This signifies that this species is well-distributed and maintains a balance within the ecosystem. Other species, such as Blue Mormon, Common Mime, and Plain Cupid also displayed relatively high equitability, indicating a stable distribution in the park.

Table 3: Species-wise species diversity

Common Name	Shannon Index	Shannon Equitability Index	Simpson Index	Gini Simpson Index
Common Mormon	0.97	0.88	0.41	0.59
Crimson Rose	0.91	0.83	0.43	0.57
Common Rose	0.93	0.84	0.44	0.56
Tailed Jay/ Green Jay	0.87	0.79	0.47	0.53
Common Mime	1.05	0.96	0.34	0.66
Blue Mormon	0.68	0.98	0.32	0.68
Lime Butterfly	0.48	0.69	0.66	0.34
Common / Ceylon Bird wing	0.00	0.00	1.00	0.00
blue Bottle	0.00	0.00	1.00	0.00
Common Crow/ Indian Crow	0.79	0.72	0.54	0.46
Common Plam Fly	0.00	0.00	1.00	0.00
Blue Tiger	0.90	0.82	0.44	0.56
common leopard	0.44	0.40	0.61	0.39
Plain Tiger	0.55	0.50	0.66	0.34
Glassy Tiger	0.99	0.90	0.13	0.87
Peacock Pancy	0.00	0.00	1.00	0.00
Lemon Emigrant	1.09	0.99	0.34	0.66
Common Grass Yellow	0.98	0.89	0.40	0.60
Red Pierrot	0.80	0.73	0.52	0.48
Plains Cupid	0.66	0.96	0.52	0.48

Source: Prepared by Authors based on 2019,2022, and 2023 data obtained from Pinnavala Open Zoo

(Indexes Rounded to 2 Decimal Places)

However, species like the Common Leopard and Plain Tiger showed an imbalance in distribution, indicating a more uneven presence compared to other butterflies. The prevailing species, identified across the study period,

included Ceylon Bird Wing, Blue Bottle, Common Palm Fly, and Peacock Pansy. These species demonstrated limited diversity and are potential indicators of an imbalance in the butterfly population in the park.

The park's butterfly population exhibits low overall diversity, with specific species showing dominance or imbalance in distribution. The use of indices like the Shannon Equitability and Gini Simpson Indexes provides a clearer understanding of which species maintain equilibrium and which may require conservation attention due to their uneven distribution or dominance. Further measures may be needed to enhance the diversity and balance of species in the park's ecosystem.

3.2.2. Annual Species Diversity of Butterflies

According to the findings derived from both the Shannon Index and Simpson Index, moderate diversity was observed across all three years.

Table 4: Year-wise species diversity

Year	Shannon Index	Shannon Equitability Index	Simpson Index	Gini Simpson Index
2019	2.34	0.85	0.11	0.89
2022	1.64	0.64	0.29	0.71
2023	1.80	0.61	0.25	0.75

Source: Prepared by Authors based on 2019, 2022, and 2023 data obtained from Pinnavala Open Zoo

(Indexes Rounded to 2 Decimal Places)

Notably, in 2019, relatively high diversity was recorded (H= 2.34, D= 0.11), while in 2022, the diversity was considerably lower (H= 1.64, D= 0.29). However, there was an improvement in diversity in 2023, as shown in Table 4.

The evenness of species visiting the study area, as measured by the Shannon Equitability Index and Gini Simpson Index, indicates that the distribution of individuals across species remained relatively stable over all three years. Evenness exceeded 70% each year, signifying a balanced distribution. Overall, 2019 saw the highest evenness and diversity among butterfly species (EH = 0.85, G = 0.89).

Values of the diversity index given in this instance convey crucial details regarding the ecological well-being and stability of the butterflies in the park. Larger values of the Shannon Index (H) denote increased species richness and evenness, translating into a better and more robust ecosystem. In 2019, the park had the highest diversity (H = 2.34) and evenness (EH = 0.85), which implies that butterfly species were spread out more evenly and that none of the species were too dominant. This implies a healthy well-balanced ecosystem with good environmental conditions. However, the seeming decrease in diversity in 2022 (H = 1.64, EH = 0.64) indicates potential ecological stress or disturbance of habitat that may have affected species richness or distribution. The slight recovery in 2023 (H = 1.80, EH = 0.61) shows a slow recovery but is still below that of 2019. The values of the Gini Simpson Index, all higher than 0.70, also show that the park enjoys a moderate degree of species balance, even though diversity changes require ongoing monitoring and conservation. Collectively, these indices point both to the strengths and weaknesses of the park and to the need for ongoing habitat quality to support butterfly diversity.

3*.3 Temporal variations of Butterfly species in the Pinnawala park*

3.3.1.Species Diversity of Butterflies Observed monthly

The butterfly species were categorized into three groups: low diversity, medium diversity, and high diversity according to the Shannon index.

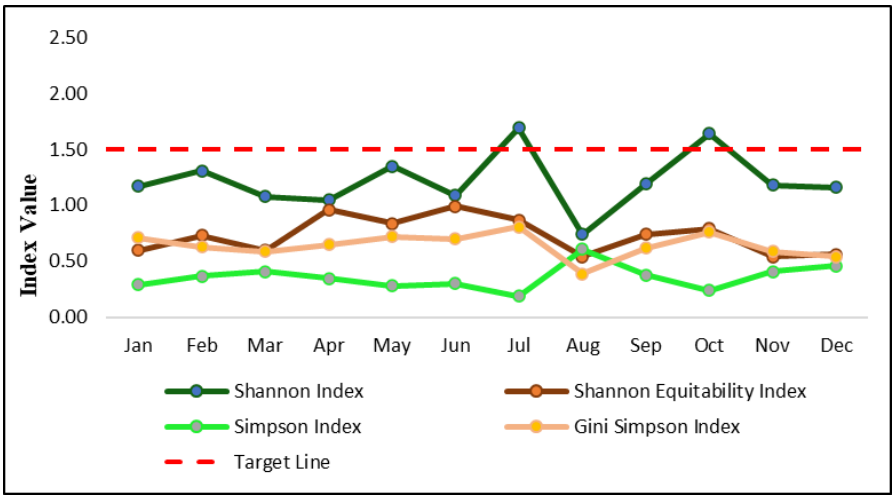

Figure 3: Species Diversity of Butterflies -2022

Source: Prepared by the Authors based on 2022 data obtained from Pinnavala Open Zoo

This classification was based on indicators observed monthly. A trend line (Target Line: H = 1.5) was drawn on the charts using the Shannon Index to clearly illustrate the division between these diversity levels. In 2022, the biodiversity indices were measured monthly, and a target line was used to assess whether species diversity met a desired level. The analysis used the Shannon Index (H), Simpson Index, and Gini-Simpson Index to gauge species diversity across the months. The Shannon Index starts at a low value of 1.17 in January, and there is a gradual decrease until April, reaching 1.05, indicating a slow decrease in species diversity during these months. The diversity saw significant fluctuations. After a peak of 1.69 in July, it drastically dropped to 0.74 in August, signalling a sharp decline in species diversity during mid-year. The Simpson Index also shows a parallel drop during this period. Diversity rebounded post-July, with the Shannon Index increasing again to 1.64 in October and then stabilizing around 1.18 from November and December, showing a slight decline towards the end of the year.

The Shannon Equitability Index and Gini-Simpson Index displayed less fluctuation throughout the year, remaining relatively stable. The months where the Shannon Index falls below the target line (around 1.5) show reduced biodiversity, notably in July and October. The highest species diversity for 2022 is observed in July, with an index of 1.69, whereas August exhibited the lowest diversity with an index of 0.74. This suggests that, while there were months with significantly high biodiversity, the diversity was not consistent throughout the year, with several months experiencing a substantial decline.

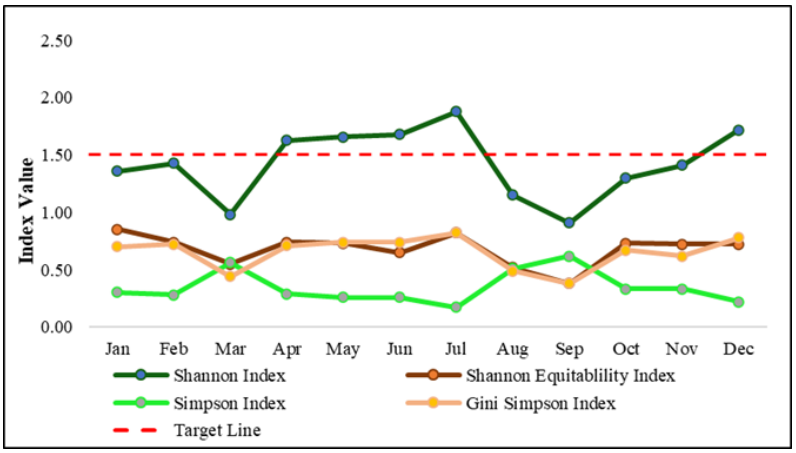

Figure 4: Species Diversity of Butterflies -2023

Source: Prepared by the Authors based on 2023 data obtained from Pinnavala Open Zoo

The figure for 2023 shows the monthly butterfly diversity variation, represented primarily by the Shannon Index and other related indices. The key observations for 2023 are: The year starts with a moderate Shannon Index value of 1.36 in January, which slightly decreases to 1.43 in February before rising again to 1.63 in April. This suggests a gradual increase in species diversity during the first quarter. The Shannon Index remains relatively high, peaking at 1.88 in July, indicating a significant rise in species diversity, which is the highest recorded value for 2023. After July, the Shannon Index declines sharply, dropping to 0.91 in September. This marks a significant reduction in species diversity during these months. The diversity bounces back after September, with the Shannon Index reaching 1.72 in December, showing an increase towards the end of the year.

The Simpson Index and Shannon Equitability Index indicate smaller fluctuations throughout the year, maintaining stability in species evenness, while the Gini Simpson Index follows a similar pattern to the Shannon Index, showing peaks during months of higher diversity and dips during months of reduced butterfly diversity.

3.3.2 Comparison Across 2019, 2022, and 2023

The year 2019 witnessed a steady increase in biodiversity from January to June, followed by a significant drop in July and then a resurgence from August onwards. The Shannon Index values mostly stayed above 1.5, with notable fluctuations. Compared to 2019, 2022 saw greater fluctuations, with lower diversity overall. There were sharper declines in the Shannon Index, particularly in July (0.74) and October (0.91), indicating inconsistent biodiversity in 2022. The year 2023 displayed moderate biodiversity at the beginning and end of the year, with a peak in June and a notable decline in September. However, 2023 was more consistent than 2022, as the Shannon Index stayed relatively higher, especially in the first half. 2022 showed more pronounced biodiversity dips compared to 2019 and 2023. 2023 had a more balanced fluctuation pattern than 2022, though its diversity did not reach the high levels seen in 2019.

2019 was a year of higher and more stable biodiversity, with a consistent performance throughout most months. 2022 exhibited more instability, with notable drops in diversity during certain months, making it a more volatile year. 2023 showed an intermediate pattern between 2019 and 2022, with moderate diversity, peaking in June, but also experiencing a drop in the middle of the year. Each year reflects different biodiversity dynamics, with 2019 being the most stable, 2022 the most volatile, and 2023 falling in between.

According to observations, several key behaviours have been identified in the butterflies within the park. Butterflies thrive in bright but not excessively hot conditions and are most active between 8:00 a.m. and 10:30 a.m., as well as later in the afternoon and early evening. Their activity decreases during periods of extreme heat and heavy rainfall, as they prefer moderately cool climates. Butterflies are often found near cooler areas, such as riverbanks and waterfalls, and they tend to rest beneath leaves at night and during the hotter parts of the day.

During 2020–2021, the COVID-19 pandemic halted conservation activities in the park. Operations, monitoring, and butterfly activities were stopped, and maintenance was restricted. As a result, egg and pupae collection stopped, no butterfly data were collected, and species richness dropped. With the easing of restrictions in late 2021, normal maintenance activities resumed. The habitats were recaptured, monitoring activity resumed, and the butterfly population gradually made-up lost ground, with increased richness reported in 2022.

4. Discussion

Observations at the butterfly park indicate that butterflies prefer bright, but not excessively hot, conditions and moderately cool climates. They are most active between 8:00 am and 10:30 am, and again in the early evening, with reduced activity during periods of increased heat and rainfall. Butterflies tend to favour cooler locations such as riverbanks and waterfalls, and they rest beneath leaves at night and during the hottest parts of the day. The key findings of this research align with several studies. For instance, sunlight is crucial for butterfly activity (Thakur et al., 2017), and large hilly areas with dense vegetation serve as resting spots for butterflies (Manzoor et al., 2013). Additionally, Mel and Yakandawala (2016) reported that butterfly activity in Kadulla National Park peaked between 7:10 am and 10:10 am, decreasing as noon temperatures rose. Furthermore, cooler winter conditions promote butterfly activity, whereas higher temperatures can lead to a decline in butterfly populations (Weerakoon & Ranawana, 2021; Silva et al., 2021).

Between 2019 2022, and 2023, a total of 7,388 individual butterflies from 20 species across 4 families were recorded within the park. The Pieridae family had the highest number of individuals, followed by Nymphalidae, which is consistent with findings from Weerakoon and Ranawana (2021) and Silva et al. (2021), who also identified these as the most abundant families in their studies.

Regarding species richness, the Papilionidae family was identified as the most dominant, while Pieridae and Lycaenidae were the least dominant in the

park. However, a study by Herath et al. (2005) on wetland mangroves at Bellanwila-Aththidiya reported Lycaenidae as the most predominant family. Although both areas are wetlands, the ecosystems differ significantly, yet observations of Papilionidae's dominance remain consistent across different studies. Meanwhile, the survey by Mel and Yakandawala (2016) recorded Nymphalidae as the most dominant butterfly family in their study site. In Silva et al. (2021), butterflies from the Pieridae family were recorded as the most dominant species, which aligns with the observations in the study. Both Kadulla and Maduru Oya National Parks, situated in the dry zone, have different geographical characteristics compared to the researcher's study area. This geographical variation highlights the influence of environmental factors on butterfly species distribution and dominance.

The analysis of butterfly species diversity in the study area indicates medium diversity across all three years. Diversity indicators show that evenness among butterfly species remained above 70% each year, with 2019 exhibiting the highest balance in species distribution. The lower diversity observed in 2020 and 2021 can be attributed to the park's reduced maintenance due to the COVID-19 pandemic. This decline in park upkeep affected food availability and habitat security, leading butterflies to migrate elsewhere.

Butterflies require specific plant types and habitat conditions to thrive, as emphasized by (Ghazanfar et al., 2016). The abundance, richness, and diversity of butterflies improved in 2023 compared to 2022. Notably, some species like Danaus genutia, Ypthima baladus, and Pierisrapae, which were not listed by the Park Management Committee, were observed during fieldwork. This suggests that the park's seasonal increase in butterfly species richness, particularly of Pelopidasmathias, is linked to the park's improved maintenance and the creation of a more suitable environment for butterflies, which in turn enhances their numbers (Jayaneththi, 2020).

5. Recommendations

The researcher can extend this research in certain directions in future studies. The objective of quantifying butterfly diversity and species richness can be explored in more depth by incorporating observations from primary data, extending beyond the application of secondary sources. This would allow for more accurate examination of butterfly species visiting the park, their diversity, migratory patterns by seasons, and variation in diversity by species and by various months from a different perspective.

Moreover, the study's pursuit of the temporal order of butterfly species diversity can be made more specific by establishing the determinants in such an order over time. Future studies should examine climatic variables like

rainfall and temperature, ecological factors, park management practices, and vegetation dynamics, providing greater insights into species diversity and its temporal fluctuations.

Butterfly species can be introduced from other areas to enhance their diversity in the park, as has been established by the successful implementation of this method in India by Thakur et al. (2019). While introducing a specific species, one needs to identify their food plant preferences, introduce host plants appropriate for them, and create the best environment for their survival. This method can be implemented effectively in Pinnawala Butterfly Park too. In addition, according to IUCN guidelines, endemic or threatened species must be preserved. Such species' conservation role can also be augmented further by the park, making Pinnawala Butterfly Park the best institution to preserve butterflies in Sri Lanka at the national level.

6. Conclusion

This study highlights the ecological value of Pinnawala Butterfly Park as an ex-situ butterfly conservation model. The findings reveal that abundance and species diversity correlate strongly with the regular maintenance in the park, and the year 2019 was the most diverse and the most stable year. The pandemic caused by the COVID-19 outbreak highlighted how vulnerable the biodiversity was to gaps in management. Seasonality and climate were also among factors influencing butterflies, particularly during mid-year. Through normal maintenance and by supplementing more host plants and species of butterflies, the park holds great potential for enhancing biodiversity and serving as an example of urban conservation. The study supports the need for the public to become aware of the environmental role played by butterflies and demonstrates how well-managed plots of land might have a vital role to play in the conservation of biodiversity.

Acknowledgments

The authors are pleased to extend their warm gratitude to the Department of National Zoological Gardens, Research & Education Division of Dehiwala National Zoo, for providing permission for this research. We are also deeply grateful to the Pinnawala Open Air Zoo for furnishing the needed data, primary and secondary, which contributed enormously towards the success of the research. We would also like to appreciate the park keepers for their openness in sharing information on butterfly species and participating in key informant interviews.

References

Bernard Tours. (2020). Pinnawala Open Zoo. Retrieved August 29, 2023, from www.bernardtours.com

Department of National Zoological Gardens. (2023). Pinnawala zoo. Retrieved August 29, 2023, from www.national.gov.lk

Elanchezhyan, K., Samraj , J. M., & Reuolin, S. J. (2017). Butterfly diversity at the agricultural college campus, Killikulam, Tamil Nadu, India. Journal of Entomology and Zoology Studies 2017, 5(5), 1389-1400. https://doi.org/www.entomolijournal.com

Herath, B. J., Henkanaththegedara, S. M., & Korala, D. J. (2005). Butterfly Fauna of Bellanwila-Attidiya Sanctuary and Its Environs, Colombo District, Sri Lanka. Sri Lanka NflTUFWLIST,01-06. https://doi.org/https://www.researchgate.net/publication/260187368

Jayaneththi, H. (2020). Butterfly Fauna of Madampa-Lake Sanctuary, Ambalangoda, Southwest Sri Lanka – Checklist Reported During 2009-2010. Journal of Ecology and Nature, 10, 1-2. https://doi.org/ https://www.researchgate.net/publication/260187368

LibreTexts Statistics. (2024). Introduction, Simpson's Index and Shannon-Weiner Index. Retrieved 5 19, 2024, from https://stats.libretexts.org/Bookshelves/Applied_Statistics/Natural_Resources_Biometrics_(Kiernan)/10%3A_Quantitative_Measures_of_Diversity_Site_Similarity_and_Habitat_Suitability/10.01%3A_Introduction__Simpsons_Index_and_Shannon-Weiner_Index#:~:text=The%

Manzoor.F et al. (2013). Butterflies as Indicators of Climate Change. ZOO's Print, 28(2).

Mel, L. M., & Yakandawala, K. (2016). Diversity and Abundance of Butterfly Fauna at the Kaudulla National Park. International Journal of Novel Research in Life Sciences, 3(2), 1-10. https://doi.org/www.noveltyjournals.com

Mathew, G. (2016). Butterfly Gardening. Pallikkutam, 33-35. https://doi.org/https://www.researchgate.net/publication/260187368

Paddy, P. (2023). Butterflies and moths: Why are they important? Retrieved July 30, 2023, from http://www.wholeearthedcation.com

Parandhaman, D., Sivasankaran, K., Meerasa, M. N., & Ignacimuthu, S. (2012). Diversity of butterflies in different habitats from Tamil Nadu part of the Western Ghats (Lepidoptera: Rhopalocera). Savarimuthu Ignacimuthu et al./ Elixir Apply Biology (15), 10861-10865.

Perera, W. P., & Bambaradeniya, C. N. (2006). Species Richness, Distribution and Conservation Status of Butterflies in Sri Lanka. The Fauna of Sri Lanka, 53-64.

Poorten.N, Poorten G.M. (2016). The Butterfly Fauna Of Sri Lanka. https://doi.org/https://www.researchgate.net/publication/303811740

Sanwal.C.H.et al. (2017). Habitat conservation through butterfly zone: A new approach to in situ conservation of butterflies. Journal of Entomology and Zoology Studies, 5(6), 2195-2199.

Samarasinghe.M.D.P. et al. (1998). Survey of the Butterflies of Udawalawa National Park. Jayawardenepura Second Annual Forestry Symposium.

Silva, P., Dasanayake, T., Jayasekara, D., & Meegamage, P. (2021). Butterfly species richness, diversity, and temporal variation in Maduru Oya National Park, Sri Lanka. Biodiversity Journal, 12(3), 741–754. https://doi.org/https://www.biodiversityjournal.com

Smetacek, P. (2002). The Study of Butterflies' Defence and Defensive Behaviour. Resonance.

Supriatna, J. (2018). Biodiversity Indexes: Value and Evaluation Purposes. EDP Sciences.

Thakur, D. C., Chakrabarti, P., & Chaudhuri, A. (2017). An approach for butterfly conservation through setting up a garden in an urban area, Kolkata, India. World Scientific News, II(61), 69-85.

Weerakoon, B., & Ranawana, K. (2021). Seasonality and movement patterns of butterflies in an intermediate zone regenerating forest habitat in Sri Lanka. International Academy of Ecology and Environmental Science, 10(4), 120-129.