

**A STUDY OF LEPIDOPTERA BIODIVERSITY
INCLUDING SPECIES RICHNESS, EVENNESS
AND ABUNDANCE IN FOUR DIFFERENT
ECOSYSTEMS OF KOTA, RAJASTHAN, INDIA**



A Thesis
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Award of the Degree of
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In
Zoology
Under the
Faculty of Science

Submitted by
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शोध निदेशालय
कोटा विश्वविद्यालय

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I feel great pleasure in certifying that the Ph.D. thesis entitled “**A Study of Lepidoptera Biodiversity Including Species Richness, Evenness and Abundance in Four Different Ecosystems of Kota, Rajasthan, India**” submitted by **Mrs. Kiran Gocher** to the University of Kota in the partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy is based on the research work carried out under my guidance.

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DECLARATION

I, **Kiran Gocher**, hereby certify that the research work presented in my Ph.D. thesis entitled “**A Study of Lepidoptera Biodiversity Including Species Richness, Evenness and Abundance in Four Different Ecosystems of Kota, Rajasthan, India**” which is carried out by me under the supervision of **Prof. Kusum Dang** and submitted in the partial fulfilment of the requirement for the award of the degree of Doctor of Philosophy of the University of Kota, represents my ideas in my own words and where others’ ideas or words have been included in this thesis, I have adequately cited and referenced the original sources.

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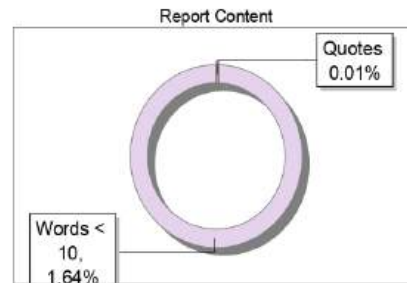
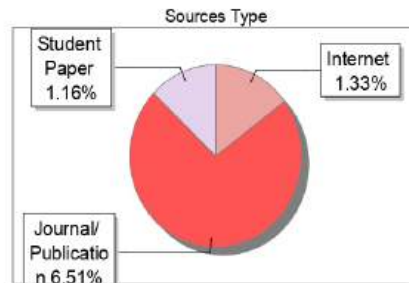
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A WORD OF GRATITUDE

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Kiran Gocher
Research Scholar

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Abstract

Butterflies are widely recognized as important bioindicators of ecosystem health due to their sensitivity to environmental changes and habitat quality. Monitoring butterfly diversity, abundance, richness, and evenness provides key understanding into community structure and ecological balance. In the present investigation biodiversity study of butterflies was carried out in semi-arid zone, Kota and its adjoining villages, Rajasthan, India. Data was recorded from four different sites- site 1 (managed urban garden), site 2 (habitat situated near water body), site 3 (agro area) and site 4 (natural landscape near forest). Study was carried out for three years (March 2022- February 2025). This study focused on variation in butterfly communities across different ecosystems. It assessed how habitat type, human activities, and the resource availability influence the species richness and distribution. The results help to explain the key ecological factors affecting butterfly populations and provide direction for conserving biodiversity and managing habitats in a sustainable way.

All the sites were visited at regular intervals. Butterflies were observed between 7 am to 11 am and in evening 4 pm to 6 pm. To identify the butterflies, they were caught using aerial net, photographed and then safely released back into the environment. Insects were photographed using Nikon Z611. Data was analyzed using Shannon-Weiner Index, Simpson Index, Margalef's Index and Pielou's Index .

A total of 5198 individuals of butterflies were recorded from the study sites representing 38 species belonging to 27 genera and 5 families. Throughout the study period, Nymphalidae had the highest percentage of species composition. While Hesperidae showed the lowest percentage of species composition at site 1 and site 4. During the study period, the highest species richness was consistently recorded at Site 4, a relatively undisturbed natural area, whereas the low richness was observed in areas affected by indiscriminate cutting of plants and within agricultural land. The highest community evenness was observed in the natural

area followed by high evenness within agricultural land. Butterfly community evenness was relatively low in gardens and habitat near water body.

The highest butterfly diversity was observed in natural area and garden, whereas lower diversity was recorded in agricultural land and habitat near water body. The abundance and diversity was higher during the post-monsoon season in the study area and was found lowest during winter season. The study also highlighted the negative impact of pesticide use, which reduced species richness and abundance.

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ABBRIVATION

IIFM	: Indian Institute of Forest Management
IUCN	: International Union for Conservation of Nature
IPPM	: Integrated Pest and Pollinator Management
SHUATS	: Sam Higginbottom University of Agriculture, Technology and Sciences
TFRI	: Tropical Forest Research Institute
WLPA	: Wild Life (Protection) Act

CHAPTER-1
INTRODUCTION

CHAPTER-1

INTRODUCTION

Insects form the largest group of living organisms and contribute significantly to biodiversity at multiple levels. They participate in essential ecological processes such as pollination, degradation of organic material, nutrient recycling, and serving as a food source for many other animals. Because of their enormous diversity in form, function, and habitat, insects maintain the balance of ecosystems and directly influence the survival of plants, animals, and humans. Their presence and abundance therefore act as an important indicator of overall biodiversity and ecosystem health.

Lepidoptera, which include butterflies and moths, are one of the most diverse groups of insects and play multiple roles in biodiversity. They act as pollinators for a wide range of flowering plants, contribute to food webs by serving as prey for birds, reptiles, and other animals, and also function as herbivores that regulate plant populations. Their rich diversity and ecological interactions make them essential for maintaining balance and stability in natural communities.

Butterflies hold ecological as well as cultural importance in biodiversity. Their colourful appearance and graceful flight also provide aesthetic and educational value, making them symbols of natural beauty and environmental awareness. In addition, butterflies are highly responsive to habitat quality and climate shifts, which makes them reliable bioindicators for assessing the health and stability of ecosystems.

Butterflies have a life cycle with four stages: egg, caterpillar (larva), pupa (chrysalis), and adult. It starts when the female lays eggs on a host plant, so the young caterpillars have food to eat. The caterpillar hatches and feeds on leaves, growing quickly and shedding its skin several times. When fully grown, it becomes a pupa, during which its body changes to form wings, antennae, and other adult parts. Finally, the adult butterfly emerges, feeds on nectar, and lays eggs to start the cycle again. Butterflies survive by using different food sources throughout their life cycle.

Butterflies generally have a short lifespan, but it varies depending on the species and environmental conditions. On average, most butterflies live for about two to four weeks as adults, while some smaller species may survive only a few days. Larger butterflies, such as swallowtails and monarchs, can live for several months. Monarchs are a special case because the migratory generation is capable of surviving up to eight or nine months, which is much longer than usual. If we consider the entire life cycle, from egg to adult, the lifespan of butterflies may range from a few weeks to almost a year.

Globally, about 20,000 species of butterflies have been documented, of which India harbors more than 1,500 species, reflecting its rich faunal diversity (Kehimkar, 2008; Varshney & Smetacek, 2015).

Butterfly diversity is declining because of many challenges linked to both human activities and environmental changes. The most serious threat comes from the loss of natural habitats, as forests, grasslands, and wetlands are cleared for farming, cities, and construction projects. Changing climate patterns also create problems, since temperature rise, irregular rainfall, and seasonal shifts disturb the blooming of plants that butterflies rely on for nectar and breeding (egg laying). The heavy use of pesticides in agriculture further reduces host plants and often kills butterflies directly.

Pollution from chemicals, air, and artificial lights adds to the stress on their populations, while invasive plants replace native species, cutting down food and shelter options. In some cases, rare butterflies are also over-collected for trade or ornamental purposes. Together, these pressures are causing a noticeable decline in butterfly diversity across the world. Studying butterfly communities helps researchers evaluate ecosystem stability and develop measures to protect biodiversity.

This research examined the diversity of butterflies in Kota and its adjoining villages, Rajasthan, India, across four contrasting habitat types: natural landscape near forest, managed garden spaces (urban), agricultural field used for crop production, and habitat situated near water body. Each of these ecosystems

provides distinct ecological conditions that shape butterfly communities in different ways. By comparing these sites, the study aims to highlight how habitat characteristics and human activities influence species diversity, richness, abundance and distribution, thereby offering insights into the ways ecosystems either sustain or reduce biodiversity.

The objective of this research work is:

1. To document the butterfly diversity occurring within the selected study area.
2. To assess the relative abundance and seasonality of butterflies in the selected sites.
3. To analyze the family wise percentage composition of species.
4. To measure the species richness and evenness across four distinct ecosystem types.
5. In this research, the Similarity and dissimilarity Index was used to compare the species composition and determine the degree of overlap among butterfly communities at different study sites.
6. In this study, an experiment was designed to examine the impact of pesticides on butterfly abundance.
7. To compare butterfly communities in natural habitat near forest, urban garden, agricultural landscape, and habitat located near water body.
8. Diversity of butterflies varies with numerous factors including the availability of host plant species. Design of the present research work will reveal significant correlation of diversity of butterflies with the availability of host plant species, anthropogenic activities and use of pesticides. So the results will provide the reason for depletion of butterfly population.

The rapid reduction in pollinator populations has become a serious concern, as it poses potential risks to global food security and threatens the balance of ecosystem processes (Potts et al., 2010). A range of human-induced factors are endangering both wild (butterflies) and managed pollinators (honeybees, bumblebees), leading to declines in their numbers, variety, and overall health, which in turn threaten the pollination service they deliver to natural vegetation as well as agricultural crops (Vanbergen, & Insect Pollinators Initiative, 2013).

Globally, the major causes behind the decline of insect pollinators are habitat modification and fragmentation (Kennedy et al., 2013), reduction in the richness and availability of floral resources (Kremen et al., 2007), indiscriminate pesticide application (Pettis et al., 2013), and the impacts of climate change (Schweiger et al., 2010). Training of farmers on safe use of pesticides and reduction of pesticides use in agriculture can protect the pollinators (Waddington et al., 2014)

The application of chemical pesticides in agricultural landscapes has a profound effect on butterfly diversity. These sprays not only reduce the availability of floral resources by contaminating nectar and pollen but also cause direct toxicity to both larval and adult stages (Dively & Kamel, 2012). Larvae often feed on host plants treated with insecticides, leading to high mortality before reaching maturity. Adults, on the other hand, are exposed while visiting flowers or through contact with pesticide residues on vegetation. Over time, repeated chemical exposure disrupts natural population balance, reduces reproductive success, and results in the decline of sensitive species, while only a few tolerant forms may survive. This shift leads to decreased species richness, uneven community composition, and overall reduction in pollination services. Therefore, indiscriminate pesticide use acts as a major driver of butterfly population decline, highlighting the urgent need for eco-friendly pest control methods and integrated approaches that safeguard both crop production and biodiversity.

Natural habitats with insignificant or no human disturbance provide the most favourable conditions for butterflies to survive and adapt. Similarly, gardens enriched with nectar-producing and host plants can sustain a variety of butterfly species. However, many farmers remain unaware of the ecological benefits butterflies offer as pollinators. Therefore, farmer awareness and training programs are essential to encourage the use of Integrated Pest and Pollinator Management (IPPM) practices, which help to minimize excessive dependence on chemical pesticides for crop production (Meissle et al., 2010). Such initiatives can motivate farmers to conserve beneficial insect fauna. In addition, adopting measures such as habitat management and the use of safer alternatives to chemical pesticides will further support pollinator conservation. Wetland edges and water-associated

habitats are also important, as they attract butterfly species adapted to moist environments and reliant on specific host plants.

Butterflies belong to the order Lepidoptera and are classified into several families. The most widespread families include-

Nymphalidae, often called brush-footed butterflies, which are known for their large size and brightly patterned wings. Being the most diverse family, they occupy a wide range of habitats. They play a major role in nectar foraging and thereby sustain pollination networks. The larvae feed on multiple plant species, sometimes controlling weed growth. Due to their sensitivity to habitat changes, they act as bioindicators of ecosystem health. The common examples are *Danaus chrysippus* (plain tiger) & *Junonia orithya* (blue Pansy).

Pieridae (whites and yellows), commonly found around fields and gardens thus ensuring cross-pollination of crops and weeds. Some species are considered agricultural pests, which highlights their role in influencing crop–insect interactions. Their seasonal population changes serve as useful indicators of climate variation. *Eurema hecabe* (common grass yellow) is the most common example of this family.

Papilionidae, the swallowtails, which are usually large with characteristic tail-like extensions on their wings. They contribute to pollination of many wild and cultivated plants. Larvae are specialized feeders on certain host plants, helping regulate plant populations. By acting as flagship species, they also promote biodiversity awareness and conservation efforts. *Papilio polytes* (common mormon) is the most frequently observed species of this family.

Lycaenidae (blues and coppers), family butterflies are small in size but highly diverse. They often share mutualistic relationships with ants (myrmecophily), influencing insect community dynamics. Many species are effective pollinators of small wild flowers. Their wide range of host plants adds to ecosystem complexity and resilience. Because of their small size and rapid population responses, they

are sensitive indicators of habitat disturbance. For example- *Pseudozizeeria maha* (pale grass blue).

Hesperiidae, the skippers, are recognized by their rapid, darting flight. These families differ in appearance, behavior, and habitat preference. They contribute to energy flow by serving as prey for birds, reptiles, and other insectivores. Their adaptability makes them important in maintaining ecological balance across disturbed habitats. For example- *Borbo cinnara* (rice swift).

Investigating butterflies as bioindicators is vital for conservation initiatives, ecosystem monitoring, and assessing overall ecological health. Through examining species richness, abundance, and diversity indices, this research highlights how habitat features and land-use patterns shape butterfly populations. The loss of nectar sources and the drying of host plants directly contribute to butterfly mortality and influence their migratory movements.

Findings from this work can support the restoration of biodiversity and guide the development of suitable management strategies to safeguard butterfly diversity and the ecological services they provide. For the Kota region in particular, only limited information exists regarding butterfly assemblages. Therefore, the outcomes of this study offer baseline data on ecosystem condition, underline the urgency of preventing habitat degradation, and emphasize the need for long-term measures to conserve butterfly biodiversity.

CHAPTER-2
REVIEW OF LITERATURE

CHAPTER-2

REVIEW OF LITERATURE

Kitahara et al. (2000) analyzed butterfly communities along a human disturbance gradient by classifying species as generalists and specialists based on voltinism (seasonal activity) and larval resource breadth. They observed systematic changes in community structure and species composition along the disturbance gradient.

They conducted the study at the foot of Mt. Fuji, central Japan, where five grassland butterfly communities of varying disturbance levels were monitored twice monthly using the line transect method. They concluded that increasing human disturbance correlated strongly and negatively with species richness. Specialist species declined with disturbance, while generalist numbers remained stable. Species richness was more closely linked to specialist abundance, and generalists had wider community distributions.

Kunte (2001) reported the distribution of 104 butterfly species recorded around Pune, reveals distinct habitat-related patterns. Denser forest habitats, such as the valleys of Sinhagad and Peacock Bay, support over two-thirds of the species, with 11 species found exclusively there. Scrub habitats are the most species-rich habitats hosting three-fourths of the species, although only two are exclusive to scrub habitats. Forests, while slightly lower in overall richness, showed the highest species uniqueness. Plantations supported low diversity but included two unique species. Agricultural areas had relatively high species richness, while grasslands showed the lowest, with neither hosting exclusive species. Overall, wilderness areas (forest, scrub, grassland) collectively support three-fourths of the butterfly species, with about a quarter being unique to these zones. In contrast, more human-impacted habitats (plantations and agriculture) host about two-thirds of the species, some of which depend on larval host plants found in nearby wilderness areas.

Krauss et al. (2003) investigated the habitat fragmentation in insect communities overlook the role of the surrounding landscape and treat species uniformly. Addressing this gap, recent research examined how habitat fragmentation and

landscape context differentially impact butterfly specialists and generalists. In a survey of 15,185 individuals across 54 species, both specialist and generalist species richness increased with habitat area. However, species–area relationships were significantly steeper for specialists than for generalists, indicating greater sensitivity to area reduction. Landscape diversity positively influenced generalist richness, but not specialists, and this effect was scale-dependent, significant only within a 250 m radius. Neither specialist nor generalist richness was affected by habitat isolation. Furthermore, specialist density increased significantly with habitat area, while generalist density showed only a marginal increase. Isolation and landscape diversity had no significant effects on density for either group. Overall, these findings highlight the greater vulnerability of specialists to habitat loss and the scale-specific role of landscape context for generalists.

Palot and Soniya (2005) studied the butterfly-flower interaction in Keoladeo National Park in Bharatpur, Rajasthan. In the study 15 species of butterflies of 5 families were recorded. The park was dominated by Pieridae family followed by Nymphalidae, Lycaenidae and Danaidae. Only one species of Hesperidae was recorded. The flowering plants were also observed during study. The flowers of *Blumea* species bloom during April-May, were most preferred by butterflies.

Potts et al. (2010) stated in their study that pollinators play a critical role in global biodiversity, supporting the reproduction of both crops and wild plants. Recent evidence highlights significant decline in both wild and domesticated pollinator populations, which are paralleled by decline in the plants dependent on them. They examined the extent and causes of pollinator loss, including habitat destruction, fragmentation, agrochemical use, pathogens, invasive species, and climate change, as well as their interactions. The loss of pollinators threatens essential pollination services, with serious ecological and economic consequences that could affect plant diversity, ecosystem stability, crop yields, food security, and human well-being.

Schweiger et al. (2010) mentioned in their study that global change poses major challenges to biodiversity and ecosystem functioning, yet its impact on critical biotic interactions, such as plant-pollinator relationships, remains underexplored.

They investigated the combined effects of climate change and alien species introduction-two prominent drivers of anthropogenic change-on plant-pollinator interactions. Climatic shifts and species invasions can disrupt existing ecological relationships, leading to novel communities where some interactions disappear and new ones form. While alien species may sometimes mitigate the negative effects of climate change, they can also intensify them. Notably, such compensatory effects are often limited to generalist species, leaving specialist, native interactions are particularly vulnerable. These findings highlight the urgent need for research focused on understanding and predicting interactive environmental impacts on species interactions.

Hussain et al. (2011) conducted study on the butterflies existing in the campus of the Department of Atomic Energy (DAE) at Kalpakkam. They investigated the seasonal population dynamics of butterflies through a systematic monitoring approach. Researchers established a permanent 300-meter line transect, recording all butterfly species observed within a 5-meter radius. The survey documented a total of 2,177 individuals, representing 56 species across five butterfly families: Nymphalidae, Pieridae, Lycaenidae, Papilionidae, and Hesperidae. Among these, the Nymphalidae family emerged as the most dominant throughout the all seasons. The greatest species richness and population abundance were recorded during the northeast monsoon and winter months. These findings suggest that butterflies in the southern plains of India exhibit a preference for cooler climatic conditions for breeding and emergence. Specifically, two consistent trends were noticed that there was dominance of Nymphalidae family and peak butterfly abundance was observed in the wet season.

Tiple (2011) recorded the butterflies of Vidarbha region, Maharashtra, Central India. In total approximately 167 species of butterflies, belonging to 90 genera representing five families were reported based on previous studies in this region. Unusual record of seven species was also reported from this region by previous workers.

Roy et al. (2012) documented the butterfly diversity and abundance with reference to habitat heterogeneity in and around Neora Valley National Park,

West Bengal, India. Diversity and abundance of butterflies was recorded from 3 different habitats-thick vegetation assemblage with closed canopy cover, edge of forest and areas of human intervention during April-May 2010. In the study highest butterfly diversity and abundance was reported from the areas of forest edges, whereas dense forest and areas with human habitat showed lower butterfly diversity and abundance. The outcome of this research indicates the negative influence of anthropogenic intervention on the butterfly diversity in the study area.

Tiple (2012) conducted survey on the TFRI campus, Jabalpur, Madhya Pradesh, Central India, documented 66 butterfly species across five families-Papilionidae, Pieridae, Nymphalidae, Lycaenidae, and Hesperiiidae. Of these, a few species such as *Papilio demoleus*, *Catopsilia pomona*, *Eurema hecabe*, *Danaus chrysippus*, and *Euploea core* were found year-round, while the majority appeared mainly during the monsoon to early winter months. Seasonal fluctuations were evident, with peak abundance recorded from June to November and sharp declines during late winter and summer, consistent with earlier reports from Central India.

The study also highlighted conservation concerns: five species were protected under the WLPA, 1972, and overall butterfly richness was negatively influenced by habitat disturbance from landscaping activities. These results stress the role of institutional campuses as potential butterfly habitats, where sustainable management of gardens and vegetation can enhance both biodiversity conservation and future research opportunities.

Khandokar et al. (2013) evaluated the species diversity and abundance of butterflies in the Lawachara National Park, Bangladesh. In the study 159 species of butterflies were observed and 3 new species of butterflies were recorded from the study area. Maximum number of butterflies were recorded during summer season (April to June). During the study 28 species were most abundant, 56 species moderately abundant and 76 species were less abundant.

Ghorai and Sengupta (2014) studied the altitudinal distribution of Papilionidae butterflies in the East Himalayan Landscape of West Bengal, India. Their study reveals distinct patterns across 11 elevation belts of the 26 recorded species. Species richness (R) and diversity (H') peaked between 1200–1400 meters above sea level, while both metrics were lowest above 3000 meters. Butterfly abundance similarly declined with elevation, with the highest number of individuals found between 900–1100 meters and the fewest above 3000 meters. Larval host plant availability, represented by 35 plant species across six families, likely plays a key role in shaping these distribution patterns. Notably, 30.77% of butterfly species were strictly monophagous, underscoring the strong host plant specificity within this group.

Harsh (2014) conducted a comprehensive study to assess butterfly diversity in the campus of the IIFM, Bhopal, over a six-month period. The survey documented a total of 55 butterfly species across five major families: Hesperidae (7 species), Papilionidae (4 species), Pieridae (10 species), Lycaenidae (13 species), and Nymphalidae (21 species). The butterflies were recorded from three distinct habitat types within the campus—open scrubland, dry deciduous forest, and urbanized areas. The open scrub habitat exhibited the highest species diversity, with a Shannon index value of 3.76, indicating a rich and well-distributed butterfly population.

Among the 55 species recorded, *Eurema brigitta* emerged as the most dominant species. The abundance of these species is likely attributed to the availability of their specific larval and host plants within the study area, highlighting the influence of vegetation composition on butterfly populations. This study underscores the ecological richness of the IIFM campus and demonstrates how varied habitats, even within urban and semi-natural environments, can support significant butterfly diversity.

Nair et al. (2014) they carried out the study on the diversity and abundance of butterfly (Lepidoptera:Rhopalocerca) fauna in and around Sarojini Naidu College Campus, Kolkata, West Bengal, India. In the study 49 species of butterflies of 5 families and 36 genera were recorded from May, 2013 to April, 2014. The study

area was dominated by Nymphalidae, followed by Lycaenidae, Pieridae, Papilionidae, and Hesperidae. From the species recorded, 5 species come under the Indian Wildlife Protection Act, 1972.

Sethy et al. (2014) studied the butterfly species diversity in Namdapha Tiger Reserve, in Changlong district, Arunachal Pradesh, during 2008-2009. From the study 1,415 butterflies belonging to 113 species covering, 73 genera and 5 families were recorded. The area was dominated by Nymphalidae family followed by Papilionidae, Lycaenidae, Pieridae and Hesperidae.

Alarape et al. (2015) evaluated the butterfly species diversity and abundance in University of Ibadan Botanical Garden, Nigeria. In the study checklist was made comprising a total of 57 butterfly species belonging to 9 families.

Ojianwuna (2015) investigated the impact of climatic variables affecting the diversity and abundance of butterflies in Okumu National Park, Edo state, Nigeria. In this study butterflies were observed from July to November, 2012 using baited traps and butterfly nets. Total 76 species belonging to 5 families were captured and identified in the study area. Diversity of butterflies was calculated in 3 ranges. Arakhuan range ($H=3.618$) showed highest diversity and in Igwuowan range ($H=2.997$) lowest diversity was found. From the study it has been reported that temperature was positively correlated with the total number of individuals and species while rainfall was negatively correlated with the total number of individuals and species.

Sharma (2015) in her study recorded 40 species of butterflies in the study area (Ajmer, Rajasthan, India). These species belong to 8 families viz. Danaidae, Hesperidae, Lybitheidae, Lycaenidae, Nymphalidae, Papilionidae, Pieridae and Satyridae. In the present study Pieridae was reported most dominant family represented by 17 species, followed by Nymphalidae (9 species), Papilionidae (4 species), Danaidae and Satyridae both with 3 species and Lycaenidae with 2 species. Hesperidae and Acraeidae were found least abundant in the study area. In her study she revealed that *Danaus chrysippus* and *Catopsilia etrida* were the

first to emerge (March) and *Papilio demoleus* emerged in the month of April. The Peak butterfly activity was observed in the month of April and October.

Antony et al. (2016) in their study examined the diversity of butterfly species at the Kariavattom Campus, University of Kerala, where survey was conducted across four distinct study sites. A total of 105 butterfly species were documented, showing significant biodiversity within the campus area. The family Nymphalidae emerged as the most dominant group with 40 species, followed by Lycaenidae (23 species), Hesperidae (18 species), Pieridae (13 species), and Papilionidae (11 species). The dominance of Nymphalidae was evident in both species count and individual abundance, indicating their ecological adaptability and preference for the local habitats. At Site 3 (Botany Garden) highest butterfly diversity was recorded (83 species), followed by Site 1 (Medicinal Garden) with 65 species, Site 2 (Mixed Vegetation) with 32 species, and Site 4 (Grassland) with just 9 species. Seasonal variation in butterfly sightings was also observed, with peak diversity recorded during the months of June and May, and the lowest in March and April.

Out of the recorded species at the study site, 21 species of butterflies are listed under the Indian Wildlife (Protection) Act, 1972, with 8 species falling under various protected schedules. Additionally, 9 species were identified as endemic to the Western Ghats, underscoring the ecological importance of the campus as a refuge for both common and conservation-priority species. This study not only contributes valuable data to regional butterfly biodiversity but also emphasizes the conservation value of urban green spaces like Kariavattom Campus in sustaining butterfly populations, including endemic and protected species.

Kulshrestha and Jain (2016) carried out the assessment of diversity of butterfly species at Jhalawar, Rajasthan, India. In this study butterflies were collected from 3 regions of Jhalawar namely College Campus, Shree Jairaj Park and Jhiri area. In the study area 20 species of butterflies belonging to 4 families were collected. All the areas were dominated by Pieridae and Nymphalidae followed by Papilionidae and Lycaenidae. It was also noted that College Campus and Jairaj Park characterised by similar type of vegetation, trees and ornamental plants that is why these areas are dominated by similar species.

Panda et al. (2016) they evaluated the species diversity of butterflies in the urbanizing areas of Bhubaneswar. Photographic survey was conducted for one year across various habitat types, including forest cover, undisturbed shrub lands, swamps, parks and gardens, and human settlements, to document butterfly species diversity. A total of 101 butterfly species were recorded, spanning across five families: Nymphalidae (35 species), Lycaenidae (28 species), Pieridae (16 species), Hesperidae (14 species) and Papilionidae (8 species).

The highest species richness was observed in forest areas, where 84 species (83.1%) were found. This was followed by 41 species (40.6%) in undisturbed shrub habitats, while the lowest diversity was recorded in areas with human habitation. The study also reported that 10 butterfly species (9.9%) are legally protected under the Wildlife (Protection) Act, 1972, of which 6 species are listed under Schedule I, requiring immediate conservation attention.

Potts et al. (2016) stated that wild and managed pollinators offer vital benefits to society, including enhancing food security, supporting farmer and beekeeper livelihoods, maintaining biodiversity and ecosystem stability. However, pollinators face several threats, such as land-use changes, climate change, pesticides, genetically modified crops, poor pollinator management, pathogens, and invasive species. While declines in both wild and managed pollinators have been well-documented in many regions, effective policies and management strategies can be implemented to protect pollinators and ensure the continuation of their crucial pollination services.

Radha (2016) emphasized that butterflies are important to grassland ecosystems not only for their beauty but also because they serve as pollinators, supporting ecosystem functions. However, habitat loss and intensive farming, especially with the use of chemicals, can greatly affect butterfly populations. This study aimed to compare butterfly diversity and pollination activity in organic farms versus pesticide-treated farms. The results showed that organic fields had higher numbers of butterflies and overall insect activity. These fields also supported a greater population of natural pollinators and beneficial insects.

Santhosh and Basavarajappa (2016) analyzed the effect of pesticides application on native butterfly fauna in agriculture ecosystems at Chamarajanagar District, Karnataka. In this study, about 45 butterfly species were observed across five families: HesperIIDae (5 species), Papilionidae (5 species), Pieridae (9 species), Lycaenidae (10 species) and Nymphalidae (16 species). Their population density and abundance showed noticeable differences between pesticide-treated fields and untreated control sites. Overall, a decline in butterfly diversity was recorded in areas exposed to pesticide sprays. Diversity indices also reflected this impact. These findings highlight how pesticide use in intensive agricultural landscapes can adversely affect butterfly survival and community structure.

Kumar (2017) studied the species diversity and distribution of butterfly fauna with heterogeneous habitats in Jhansi, India. In this study the diversity of butterfly was assessed from selected area of Jhansi. In the study, 955 individuals of butterflies were recorded constituting 29 genera and 38 species identified belonging to six families. Out of these Nymphalidae family dominated followed by Pieridae, Lycaenidae, Danaidae, HesperIIDae and Papilionidae. From the study it has been concluded that rapid urbanization is destroying the habitat of butterflies. Although Jhansi district is characterized by dry weather still 38 species occurrence reflects the healthy ecosystem.

Sharma and Sharma (2017) provided the valuable insights into the ecological significance of butterflies in the Gir Forest of Gujarat. Their study emphasizes that sanctuary sustains a wide range of insects, with butterflies serving as important ecological indicators. The findings highlight that Danaidae and Nymphalidae species dominated the butterfly community, whereas HesperIIDae family was least represented. A noteworthy outcome of the study is that butterfly richness and diversity were greater in disturbed habitats—such as areas affected by thinning, fire, or other ecological disruptions—than in dense, undisturbed forest patches. Overall, the study reinforces the role of butterflies as reliable bioindicators, whose presence and abundance can reflect broader patterns of ecosystem health and even the effects of climate.

Suhaimi et al. (2017) recorded the species diversity and abundance of butterflies (Lepidoptera:Rhopalocerca) at different altitudes along the Raub Corridor of Fraser's Hill, Pahang, Malaysia. In the study 716 individuals from 138 species of butterflies of 5 families have been recorded. Nymphalidae was the most dominant and abundant family. Species diversity, evenness and richness were reported highest at the lowest altitude. Variation in the number of species recorded at different altitude is due to variation in habitat, climatic factors, host and food plants for the butterflies.

Daniel et al. (2018) conducted a study at the Tamil Nadu Agricultural University (TNAU) campus in Coimbatore with the main goal of documenting butterfly species and creating baseline data for future research. Study site was surveyed for one year. They recorded a total of 77 butterfly species across five families. In terms of family dominance, Nymphalidae was the most common (37.67% of total species), followed by Lycaenidae (22.07%), Pieridae (16.89%), and the least represented families were Hesperidae and Papilionidae (11.69%). The findings highlighted the rich butterfly diversity within the university campus and suggests that different habitat types support varying levels of species richness.

Gandhi et al. (2018) conducted a study around the Wadhvana Irrigation Reservoir (WIR) to assess butterfly species diversity. Study was carried out for three years. In total, 42 butterfly species were recorded in their study. The most common family was Nymphalidae (38%), followed by Pieridae (31%), Lycaenidae (21%), and Papilionidae (10%). Out of these 42 species, only three species were found to be abundant, while most were classified as rare or uncommon. Butterfly abundance was found to vary significantly depending on the season. The findings suggest that Wadhvana Reservoir provides a suitable habitat for a range of butterfly species, including some that may need conservation support.

Sayeswara (2018) executed an initial survey of butterfly species at Gandhi Park, Shivamogga, Karnataka, between July and November 2016. A total of 36 butterfly species across 27 genera and five families were recorded. Nymphalidae was most dominant family, with 16 species, followed by Papilionidae and Pieridae each

with 8 species. Lycaenidae had 3 species, and Hesperidae had only one species. The study, categorized the species into common, uncommon, and rare groups, with two species being very common, nine common, thirteen not rare, and twelve rare. This survey provides important baseline data on butterfly diversity in the area, contributing to future studies.

Sekarappa et al. (2018) documented the butterfly species composition and diversity in a protected area of Karnataka, India. In this study diversity of butterflies was recorded at six forest ranges in Nagarahole National Park (NPP). During the study 138 butterfly species were recorded from 94 genera, which belong to 5 families- Hesperidae, Lycaenidae, Nymphalidae, Papilionidae and Pieridae. Species composition varied significantly among forest ranges in NPP, 113 butterfly species were common at different forest ranges in NPP, but 25 species were confined to specific forest ranges. Nymphalidae had the highest (47) species composition compared to other families. The genus *Junonia* was represented by six species followed by *Papilio* and *Eurema* with five species each. The Simpson and Shannon (equitability) indices were 0.98 and 0.94, suggesting evenness between the six forest ranges.

Abdullahi et al. (2019) studied the butterfly diversity in Prayagraj district of Uttar Pradesh, India. In this study the diversity of butterfly was determined from the 3 sites namely- Company bagh, SHUATS campus and Khushrobagh. In total 316 individuals and 21 species of butterfly belong to 4 families were recorded. Nymphalidae was the richest family comprised 43% species of butterfly followed by Pieridae with 29% species, Papilionidae and Lycaenidae families were lowest with 14% species each. Among the species of the butterflies observed in the study area, 4 of them were abundant, 2 species were common while 8 species of butterflies were less common. In addition 7 species of butterflies were occasional.

Dotson (2019) performed a study of Lepidopterans in the area of Naso-Teribe territory of Panama. His study revealed that this area is a biodiversity rich zone of Lepidopterans. It was found in his study that the forest with the least human disturbance was the most biodiverse zone. Even though the forest constituted an important habitat for the Lepidopteran community, the pastures and agro-

ecological field with higher level of anthropogenic activities served as important source of species richness and the higher population levels of Lepidopterans.

Mukherjee et al. (2019) studied that the butterfly diversity is influenced by multiple factors, notably the availability of host plants. A study conducted along the urban-rural gradient of Kolkata, India, found a significant positive correlation between butterfly and plant diversity, with varying strengths across suburban, rural, and urban zones. Identifying plant species that support butterfly populations in each area can lead to targeted conservation efforts, either by promoting host plant cultivation or by understanding butterflies' generalist or specialist plant preferences. These insights offer valuable strategies for refining butterfly conservation approaches both in Kolkata and similar urbanizing regions worldwide. In the present study it was observed that the abundance of butterflies changes with the species richness of plants in all the areas.

Arya et al. (2020) carried out the study of butterfly diversity (Lepidoptera: Rhopalocera) in the temperate forest ecosystem of Binsar Wildlife Sanctuary, located in the Indian Himalayan Region. They recorded a total of 2,591 individuals, representing 46 species across 35 genera from six butterfly families, sampled along four permanent transects. Among these, 24 species were observed to be common across all transects. The family Nymphalidae was found to be the most dominant, represented by 18 genera and 22 species, followed by Pieridae (8 genera, 12 species), Lycaenidae (4 genera, 4 species), Papilionidae (2 genera, 3 species), Riodinidae (1 genus, 3 species) and Hesperidae (2 genera, 2 species). The observed differences in species and genera richness among families highlight the ecological complexity of the habitat and the diversity of larval host plants available in the region.

Choudhary and Chishty (2020) executed the impact of habitat loss and anthropogenic activities on butterflies survival. They reported that undisturbed ecosystem supports the diversity of butterflies and disturbed ecosystem leads to migration, elimination and less diverse population and even no butterflies in the area. Butterflies are very good pollinators and they play a crucial role in existence of various plant species.

Jenber and Degaga (2020) pursued a study at Gullele Botanical Garden in Central Ethiopia and examined butterfly diversity across three habitat types- natural forest, artificial forest, and grassland- using transect sampling with sweep nets. Higher abundance and species richness was recorded in grassland (162 individuals, 26 species), followed by the natural forest and artificial forest. Shannon's diversity index was highest in the grassland ($H = 3.09$). Seasonal variation was statistically significant. Autumn showed the highest diversity and richness ($H = 3.396$; $R = 6.06$), while winter had the lowest ($R = 4.10$).

Meena (2020) measured the butterfly diversity in urban areas of Udaipur City, Rajasthan, India. In the study 32 species belonging to five families were recorded. The urban area was dominated by Nymphalidae with 10 species, followed by Pieridae with 4 species, Papilionidae and Hesperidae each with 3 species. In the present study garden was found to be the most supportive habitat for the butterflies.

Pahadiya (2020) recorded two new species of butterflies from Lalsot area of Dausa district Rajasthan. For the first time species *Gezenes nostrodamous* and *Sarangesa purendra* were observed in Lalsot, Rajasthan. It was recorded that area was dominated by Lycaenidae family followed by 9 species of Nymphalidae, 8 species of Pieridae and 5 species of Hesperidae family. The area was found to be least abundant for Papilionidae represented by only 2 species.

Pradhan and Khaling (2020) explored the butterflies in the human-modified tea dominated landscape of Darjeeling Hills. The study highlighted the potential of an organic tea estate surrounded by forest in the conservation of butterflies in Darjeeling Hills, Eastern Himalayas. During the study period 71 species of butterflies were observed in the study area belonging to 43 genera and 5 families- Hesperidae, Papilionidae, Lycaenidae, Pieridae and Nymphalidae. In the tea plantation area species richness was higher as compared to secondary forest. Out of the 71 species, 21 species were common to both the habitats. All the three habitats were utilized by the butterflies. Forest edges showed the highest diversity followed by open land and forest interior. Out of these 71 species, seven species are protected in India under the Wildlife Protection Act.

Devi et al. (2021) studied the Strategies to combat the decline in pollinator's population. Protecting, restoring, enhancing or creating new habitat is the best way to conserve population of pollinators. Judicious use of pesticide is also helpful to conserve butterflies. Minimize insecticide use, avoid spraying during bloom, and switch to more pollinator-friendly pesticide will protect the butterfly habitat.

Ombugadu et al. (2021) conducted a study in April 2016 at the Federal University of Lafia, Central Nigeria. They assessed butterfly diversity and abundance in disturbed and undisturbed habitats using transect sampling. Out of 301 individuals observed, 160 were captured, representing 25 species across 5 families and 21 genera. Pieridae was the most abundant family, while *Eurema*, *Papilio*, and *Hypolycaena* were the dominant genera. Significant differences were found in butterfly abundance between disturbed and undisturbed habitats as well as between morning and evening observations. The undisturbed habitat exhibited slightly higher diversity ($H' = 2.6$) than the disturbed site ($H' = 2.5$). The findings highlighted the ecological impact of ongoing construction on campus and emphasize the importance of conserving designated green spaces.

Rani and Ahmed (2021) estimated the diversity and seasonality of butterflies in Sariska Tiger Reserve, Rajasthan. In the study it has been found that the Sariska Tiger Reserve was dominated by family Pieridae followed by Nymphalidae and Lycaenidae. While the least number of species were reported from family Papilionidae and Hesperidae. Species abundance varies in different seasons. Maximum number of species were observed during the post-monsoon followed by monsoon, summer and winter respectively. Seasonality is mainly affected by temperature and rainfall. Humidity had lesser impact on seasonality.

Sharma and Sharma (2021) explored in the study that how different type of habitats and seasonal changes affect butterfly communities in the sub-tropical areas of the Jammu region. Researchers focused on three habitat types: mosaic landscapes (a mix of natural and human-used land), urban green spaces, and natural forests. From April to December 2018, butterflies were observed and recorded along 21 randomly placed transects in these areas.

In total 6,384 butterflies were recorded, representing 118 species across 81 genera, six families, and 20 subfamilies. The findings showed that both the type of habitat and the seasons significantly affect the butterfly numbers and species makeup.

Interestingly, the mosaic landscapes had the highest butterfly richness and diversity during the wet season. Urban green areas, despite being built-up, supported more species and individuals than the natural forest sites. Each habitat had its own unique mix of butterfly species, though there was also some overlap between different locations and seasons. The study suggests that well-managed urban areas can play a vital role in protecting butterfly populations and calls for stronger efforts to conserve these valuable habitats in the Jammu region.

Singh and Ahmed (2021) in their study focused on a regenerated or secondary forest developed on previously barren private land. Through natural processes such as seed dispersal and seeding, the area has transformed into a forest ecosystem over time. To assess the ecological health of this regenerated forest, a comparative study was conducted with a nearby natural forest area in Mulshi, Maharashtra, representing a primary forest landscape. In the regenerated forest abundance of butterflies was directly proportional to the abundance of plant species in the area. A rich diversity of butterflies in the study area reflects good health of the forest. The high diversity and abundance of butterflies in the regenerated forest area suggest that such secondary forests, even though developed on previously degraded land, can evolve into viable habitats supporting significant biodiversity. This highlights the ecological value of restoration through natural regeneration and its potential role in conserving local butterfly fauna.

Keshre and Upadhya (2022) stated that butterflies are one of the most diverse and well-researched groups of insects. They conducted the survey in Narmada Nagar from August to October 2022 to document local butterfly species. This study recorded a total of 621 individual butterflies, belonging to 35 species spread across four families: Nymphalidae, Papilionidae, Lycaenidae, and Pieridae. Among these, the Nymphalidae family was the most dominant, contributing 22 species. Both Lycaenidae and Papilionidae had 5 species each, while Pieridae had

only 3. The most frequently seen species were grass yellow, common crow, and lime pansy. These butterflies were abundant likely due to the availability of their specific host plants in the area.

Mollah and Mandal (2022) in their study explored that how different levels of human activity affect butterfly species diversity in the Baruipur subdivision, located near Kolkata, West Bengal, India. Researchers selected four areas with varying degrees of human disturbance: a bird sanctuary (least disturbed), rural, suburban, and urban zones. Over the study period, a total of 80 butterfly species were recorded across all sites. The bird sanctuary, with minimal human interference, had the highest number of species (73), followed by the rural area (62), the suburban site (54), and the urban area with the lowest diversity (36 species). This pattern clearly shows that butterfly diversity decreases as human disturbance increases. The findings suggest that preserving natural habitats and increasing green spaces in urban areas are crucial for maintaining butterfly diversity. These measures aid in conserving butterflies and the wider ecological services linked to them.

Prajapat et al. (2022) study offers a comprehensive assessment of butterfly species diversity across two reserve forests in the Aravalli Range—Jhalana Reserve Forest and Galta Forest, located in Jaipur, Rajasthan. A total of 2,138 individual butterflies were recorded, representing 35 species, 23 genera, 9 subfamilies, and 5 families within the superfamily Papilionoidea. Family Pieridae emerged as the most dominant, comprising 12 species across 7 genera. This was followed by Nymphalidae with 9 species (7 genera), Lycaenidae with 8 species (6 genera), and Papilionidae with 5 species (3 genera). The family Hesperidae was least represented, with only a single species. Overall, the findings suggest that the Jhalana and Galta forests harbor a healthy and diverse butterfly population, reinforcing their ecological value and the importance of conserving these forest habitats in the Aravalli region.

Raghavendra et al. (2022) reviewed the Insects biodiversity, threat status and conservation approaches. This study highlights the poor state of insect biodiversity in the world. Over 30% of the insect species are on a decline, and

one-third is endangered. The main causes of such a decrease are habitat change and pollution. The problem stems from the expansion of agriculture over the last six decades, while the widespread and unrelenting use of synthetic pesticides has been a key driver of decline in insect population in recent years. The study concluded that unless we change our ways of producing food, pest management strategy and attitude toward ecological restoration, insect diversity will become extinct in a few decades. Hence, there is a need for raising awareness about the seriousness of the problem and the factors that contribute to the insect population decline, so that appropriate conservation measures can be prioritized and implemented.

Virani and Madavi (2022) evaluated the butterfly diversity of Isapur Wildlife Sanctuary, Maharashtra, India. In this study, 87 butterfly species under five families were observed. From the study it appears that the butterfly abundance increased from monsoon to early winter while decreased in the summer and pre monsoon due to possibly with the unavailability of nectar and the changes in temperature and humidity of the habitats concerned.

Das et al. (2023) utilized the checklist of butterfly species in 36 federal states and union territories of India to compile and refine butterfly species checklists for each region. They then analyzed patterns in species richness, including the presence of endemic species and those tied to major biogeographic zones. These patterns were examined in relation to geographic, climatic, land cover, and socioeconomic factors across these units. Their models showed that geographic variables were the most powerful predictors of butterfly species richness, followed by climate and then land cover.

Fang et al. (2023) studied the butterfly diversity at the Chenggong Campus of Yunnan University in southwestern China, a rapidly developing urban area. Researchers used the Pollard walk method to record butterflies across the campus. A total of 3,625 individual butterflies were observed, representing 50 species from 35 genera and six different families. The families Pieridae and Nymphalidae were found to have the most species, while Riodinidae had the fewest. The most common butterfly species recorded was *Pieris rapae* (commonly known as the

cabbage white). Notably, seven species listed on the IUCN Red List were also found during the survey. The composition of butterfly community changed with different seasons and habitat types.

Butterfly diversity was highest in spring and autumn and lower in summer and winter. Diversity was also higher in road habitats (such as pathways and roadside vegetation) compared to scenic or landscaped areas. The study suggests that ongoing urban development activities such as construction and landscape design, affect butterfly diversity and species composition. Therefore, to protect butterfly populations in urban areas, it is important to plan cities in ways that preserve a variety of natural habitats.

Mallick (2023) carried out a year-long study at West Bengal State University (WBSU) to document butterfly species in the campus. The research recorded a total of 74 butterfly species belonging to five different families: Nymphalidae, Lycaenidae, Hesperidae, Pieridae, and Papilionidae. Among these, the Nymphalidae family had the highest number of species, followed by Lycaenidae, Hesperidae, Pieridae, and then Papilionidae. Butterflies were recorded in various habitats within the campus, including grasslands, open forests, scrub forests, and herbaceous areas. Scrub forests were found to be the most preferred habitat. Seasonal changes had a clear impact on butterfly presence, the highest number of species was observed during the post-monsoon season, while the winter season had the fewest.

Vähätalo et al. (2023) pointed out that urban development often replaces natural habitats with buildings, roads, and ornamental green spaces, which can drastically affect local wildlife. This study looked at how urbanization has influenced moth and butterfly (lepidopteran) communities on an office campus that was built on previously forested land. The researchers compared the lepidopteran populations on the campus with those in a nearby untouched forest. A total of 2,233 lepidopteran specimens from 56 species were collected using traps placed in both areas. The findings showed that the office campus had only half as many species as the forest. Most of the species on the campus were also found in the forest, suggesting that no new species were attracted to the urban environment.

Additionally, the number of individual insects and their total weight (biomass) on the campus were only about one-fourth of what was found in the forest. The study also observed that as the amount of impervious surface (like concrete and asphalt) increased around the traps, both the number and weight of the lepidopterans dropped sharply—almost to zero when these surfaces completely surrounded the trap area. Interestingly, the insects found on the campus tended to be larger than those in the forest. This suggests that only species with strong flying ability—those that can travel longer distances—were able to survive in the fragmented urban environment.

Vairagade et al. (2024) reviewed the past research on butterfly diversity in different forest regions of India, highlighting the rich biodiversity and the importance of these ecosystems in supporting diverse butterfly species. Researchers have used many methods to study butterfly populations, including terms like very common, common, rare, very rare, moderate, and various statistical measures such as species richness and evenness index. Across the studies reviewed, the butterfly family Nymphalidae was found to be the most dominant in terms of the number of individuals observed.

Mondel et al. (2025) provided the first report on diversity of butterfly species (21 butterfly species, 4 families) from Daringbadi, Odisha.

CHAPTER-3
MATERIALS AND METHOD

CHAPTER-3

MATERIALS AND METHOD

Survey and Analysis of Literature

The literature supporting this research was collected from standard textbooks, peer-reviewed journals obtained from online web resources such as Google Scholar. Other online websites used for literature survey are- www.ifoundbutterflies.org and www.inaturalist.org etc.

Climatic Conditions during the Study Period

In the first year of study, during winter the average temperature ranged from 17.2 to 26.7 °C, rainfall varied between 3.4 and 10.3 mm, and relative humidity ranged from 22 to 44 %. In summer, temperatures ranged from 32.8 to 36.1 °C, rainfall from 6.9 to 85.9 mm, and humidity from 16 to 41 %. The monsoon season recorded temperatures between 28.9 and 30.6 °C, heavy rainfall from 261.1 to 268.0 mm, and humidity between 66 and 74 %. During the post-monsoon period, temperatures ranged from 23.3 to 29.4 °C, rainfall from 3.4 to 106.5 mm, and relative humidity from 37 to 63 %.

During the year 2023-2024, analysis of seasonal climatic parameters showed that during winter, average temperatures ranged from 17.2 to 26.7 °C, rainfall varied between 3.8 and 11.5 mm, and relative humidity ranged from 22 to 44 %. In summer, temperatures ranged from 32.8 to 36.1 °C, rainfall from 7.7 to 95.6 mm, and humidity from 16 to 41 %. The monsoon season experienced temperatures between 28.9 and 30.6 °C, heavy rainfall from 290.9 to 298.8 mm, and relative humidity between 66 and 74 %. During the post-monsoon period, temperatures ranged from 23.3 to 29.4 °C, rainfall from 3.8 to 118.8 mm, and humidity from 37 to 63 %.

In the year 2024-2025, seasonal climatic analysis showed that during winter, temperatures ranged from 17.2 to 26.7 °C, rainfall from 3.3 to 9.8 mm, and relative humidity from 22 to 44 %. In summer, temperatures ranged from 32.8 to 36.1 °C, rainfall from 6.6 to 82.2 mm, and humidity from 16 to 41 %. The monsoon season recorded temperatures between 28.9 and 30.6 °C, heavy rainfall from 250.1 to 256.8 mm, and humidity from 66 to 74 %. During the post-monsoon period, temperatures ranged from 23.3 to 29.4 °C, rainfall from 3.3 to 102.1 mm, and relative humidity from 37 to 63 %.

In January 2025, the average temperature was 17.2 °C, with rainfall measuring 10.6 mm and relative humidity at 44%. In February 2025, temperatures rose slightly to 20.6 °C, rainfall increased to 15.8 mm, and humidity decreased to 33%. These observations, compiled from WeatherSpark (2025) and adjusted using annual rainfall totals reported by the India Meteorological Department (2022–2025), provided the climatic framework for interpreting the study results.

Study Area

The present research work was carried out in Kota and its adjoining villages, Rajasthan, India. Geographical coordinates of this region stretch between approximately 24°32'N and 25°51'N latitude and 75°36'E and 76°36'E longitude. The study area belongs to the tropical semi-arid category. Summers are extremely hot with maximum temperature frequently rising up to 45°C, while winters are relatively cool with minimum temperature reaching upto 8°C. The average annual rainfall is varying between 660-760 mm. The study was carried out at four different sites- site 1 (managed garden spaces urban), site 2 (habitat situated near water body), site 3 (agricultural field used for crop production) and site 4 (natural landscape near forest).

Site 1 (Chatra Villas Garden)-

Chatra villas garden is located at Nayapura Kota just adjacent to Kishore Sagar Talab. The geographical coordinates lies between latitude 25.2012°N and longitude 75.8566°E. Area covered by C.V garden is 62.1 acres. The Chatra villas

garden is enriched with unique flora and fauna. Different plant species present in Chatra villas garden are as follows- *Lantana camara*, *Phlox* spp., *Nelumbo nucifera* and *Lagerstroemia indica*, which serve primarily as nectar sources for butterflies. *Murraya paniculata* and *Hibiscus rosa-sinensis* were also recorded, functioning both as nectar plants and as host plants for the larvae of certain butterfly species. In addition, *Azadirachta indica*, *Crinum asiaticum*, and *Leucophyllum frutescens* were reported as common ornamental plants in the garden, contributing as nectar resources for adult butterflies.



Google map of C.V garden, Nayapura, Kota (Rajasthan)

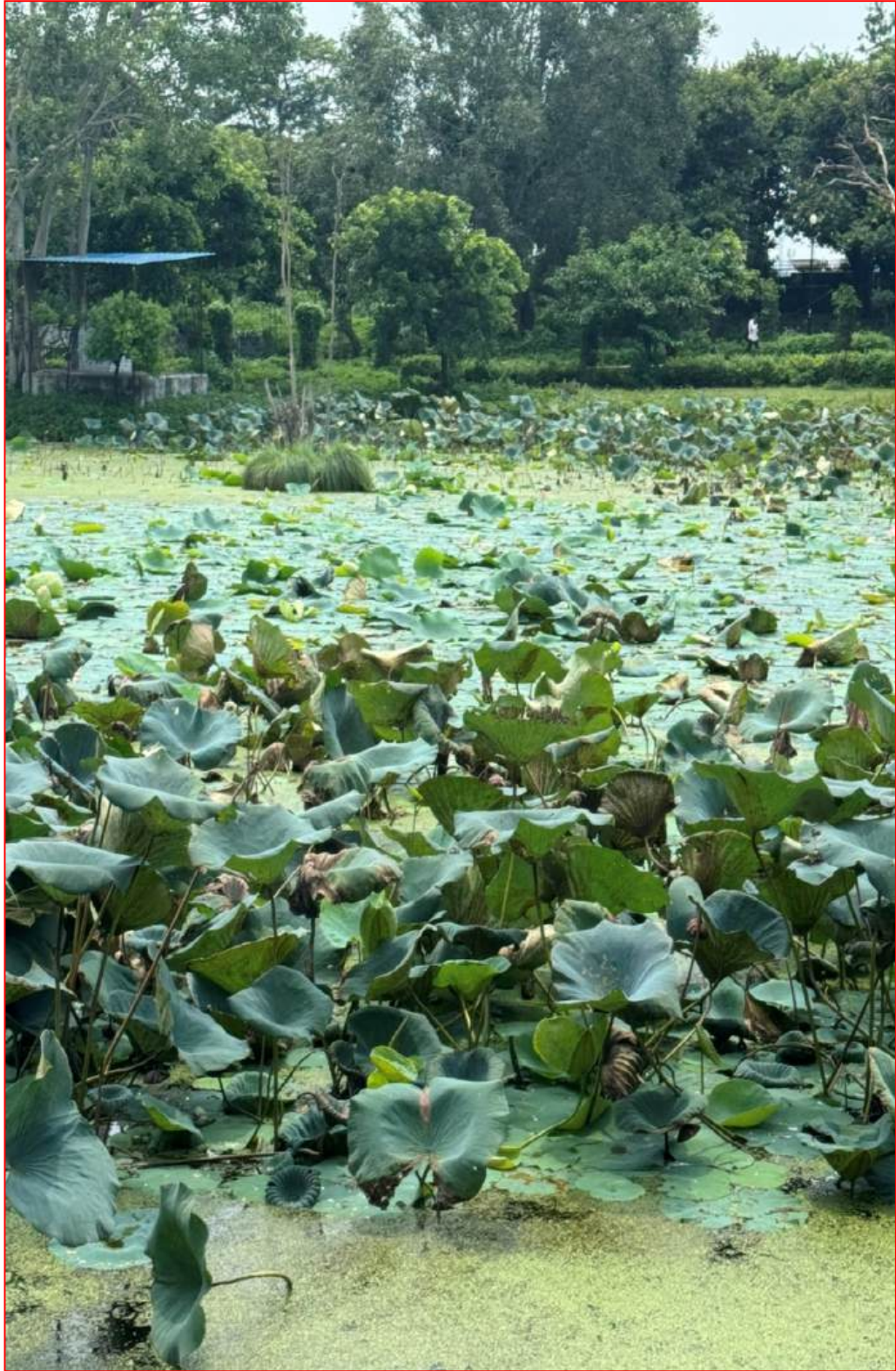
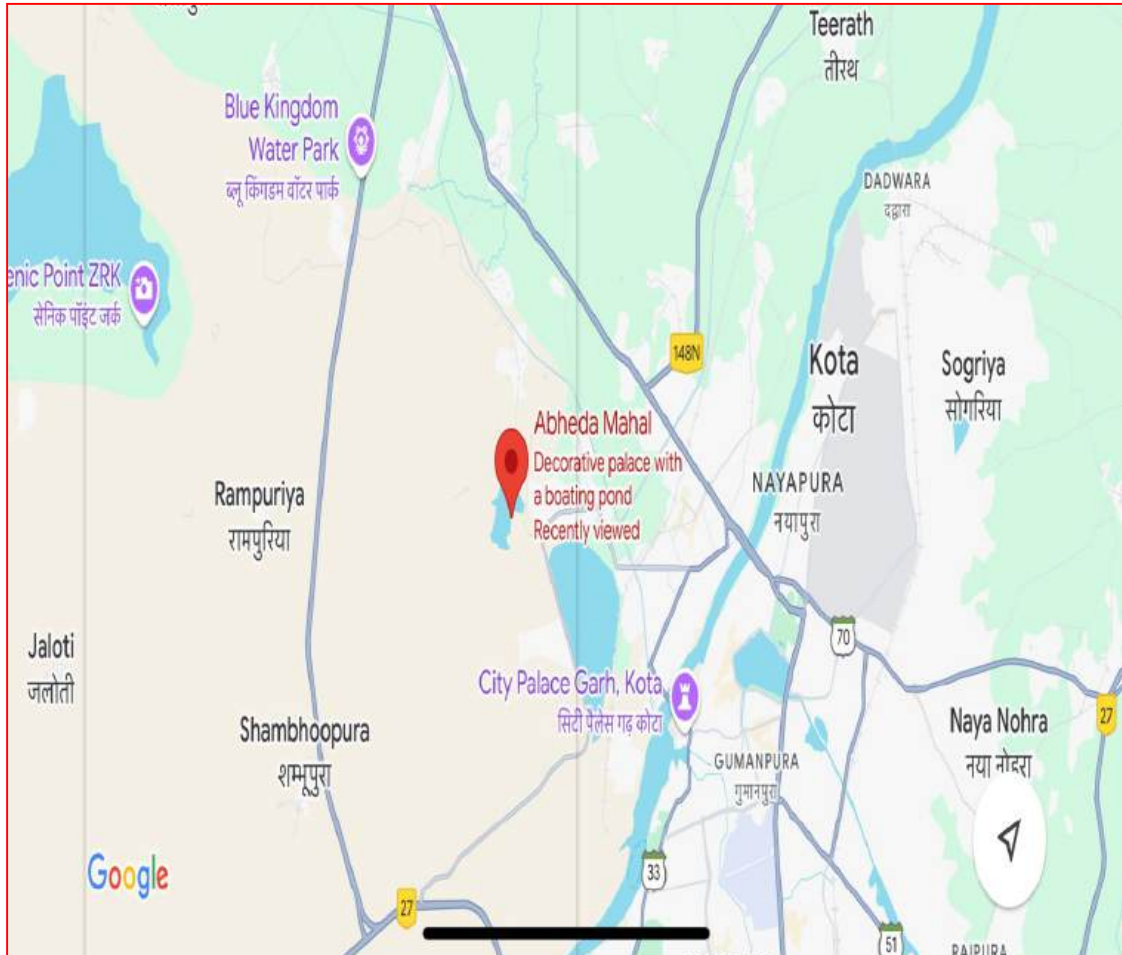


Plate-1: Study site 1, showing *Nelumbo nucifera*.

Site 2 (Abheda)-

Abheda is situated near the Chambal river of Kota, Rajasthan. The geographical coordinates of Abheda Mahal lies between latitude 25.2000°N and longitude 75.7905°E. Abheda Mahal is located about 8 Kms from the main Kota city. This area is covered by grass and various plant species like including *Limnophila indica*, *Hygrophila auriculata*, *Polygonum plebeium*, *Vallisneria spiralis*, *Ludwigia perennis*, *Caesulia axillaris*, *Bacopa monnieri*, *Potamogeton crispus* and *Eclipta prostrata*, *Hibiscus rosasinensis*, *Lantana camara*, *Acacia catechu*, *Eicchornia crassipes*, *Ficus benghalensis*, *Parthenium hysterophorus* and *Azadirachta indica* etc.



Google Map of Abheda (near the Chambal river of Kota, Rajasthan).



Plate-2: Study site 2 (Abheda-near water body)

Site 3 (Bhopatpura)-

Bhopatpura Village which is a small Village in Talera Tehsil in Bundi District of Rajasthan State, India. It comes under Bhopatpura Panchayath. The geographical coordinates of Bhopatpura Village lies between latitude 25.314676°N and longitude 75.735832°E. In this village *Rosa indica* and *Tagetes erecta* flowers are cultivated. Other crops are also cultivated in this village like *Triticum aestivum*, *Cicer arietinum* and different types of vegetables (*Spinacia oleracea*, *Raphanus sativus*, *Pisum sativum* and *capsicum frutescense*).



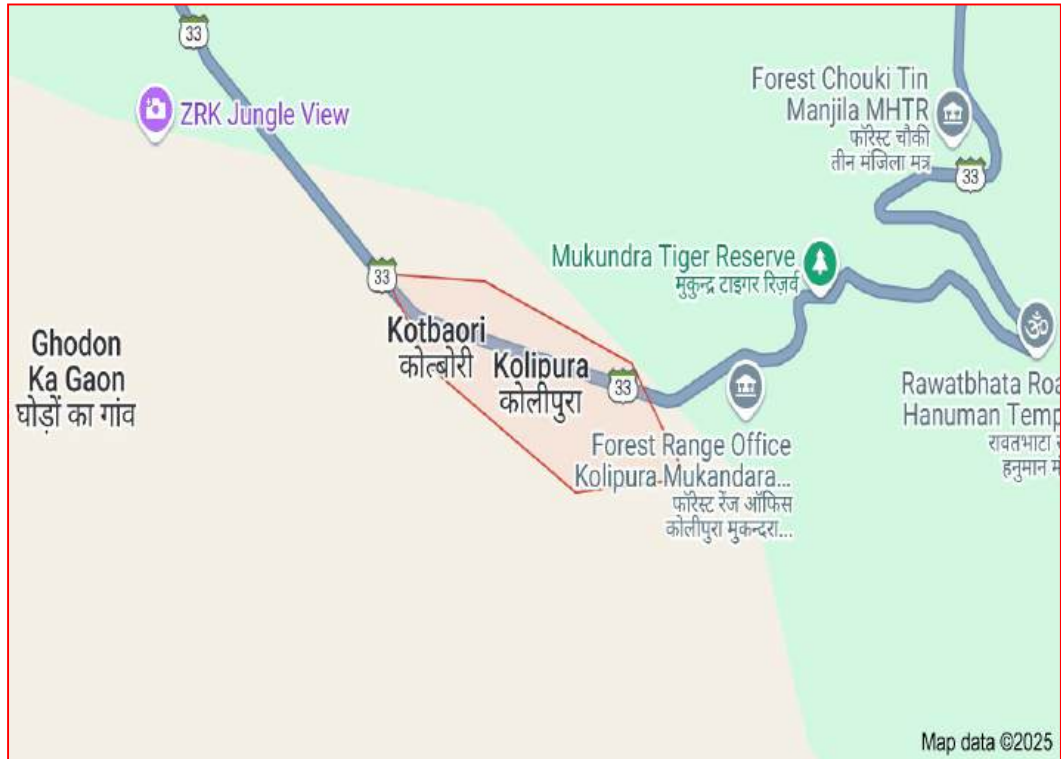
Google Map of Bhopatpura Village, Tehsil Thalera, Bundi.



Plate-3: Butterfly collection using aerial net (Site-3).

Site 4 (Kolipura)-

Kolipura Village which is located in Ladpura tehsil of Kota district in Rajasthan, India. It is situated 38km away from sub-district headquarter Ladpura (tehsildar office) and 38km away from district headquarter Kota. It is located near the Mukundra Hills Tiger Reserve which is a protected area that includes the Mukundra Hills National Park, Darrah Sanctuary, Jawahar Sagar Wildlife Sanctuary, and part of the National Gharial Sanctuary. The geographical coordinates of Kolipura village lies between latitude 25.2021°N and longitude 75.8567°E. This area is endowed with lush green vegetation. Various plant species observed at this area are as follows- *Calotropis procera*, *Lantana camara*, *Azadirachta indica*, *Flacourtia indica*, *Ziziphus mauritiana*, *Bombax ceiba*, *Murraya paniculata*, *Mangifera indica*, *Acacia catechu*, *Dalbergia latifolia*, *Terminalia spp.*, *Aegle marmelos*, *Hibiscus rosa-sinensis*, *Butea monosperma*, *Bacopa monnieri*, *Hygrophila auriculata*, *Polygonum plebeium* and *Limnophila indica*, many of which serve as important nectar sources and larval host plants for butterflies in this region



Google Map of Kolipura village, Tehsil Ladpura, Kota.



Plate-4: Study site 4 (Kolipura)

Methods of Sampling, Collection of Butterflies and Identification

The sampling was done by “Line Transect Method” during the year 2022-2023, 2023- 2024 and 2024-2025. Regular visits and butterflies were observed between 7 am to 11 am and in evening 4 pm to 6 pm. To identify the butterflies, they were caught using aerial net, photographed and then safely released back into the environment. Data was collected regularly every month and insects were photographed using Nikon Z611 & iPhone 15 Pro.

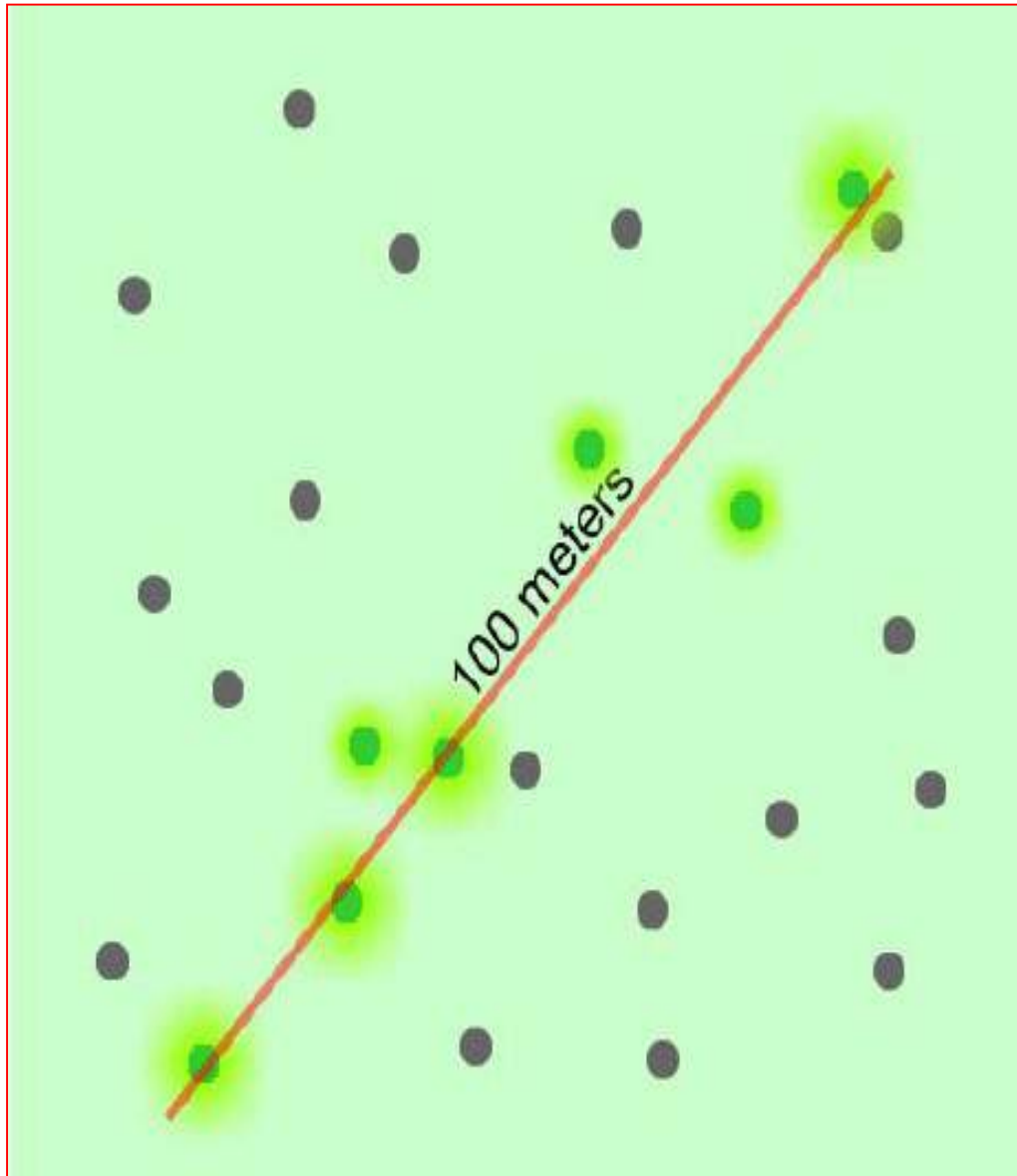


Fig 1: Line transect method showing 100 m transect line with butterflies recorded within fixed belt area -5 m left, 5 m right and 5 m above (Carthy et al., 2005).

The insects were identified based on their wings colour, pattern, shapes, sizes, with the help of entomological experts, available literature (online web resources- www.ifoundbutterflies.org, www.inaturalist.org, Butterflies of India by Arun Pratap Singh), standard field guides, catalogues and keys (Evans, 1927; Varshney and Smetacek, 2015; Kehimkar, 2016). All the scientific names follow Varshney RK & Smetacek P (2015). The identification of plants was confirmed through descriptions and images available on the Plants of Rajasthan website (Plants of Rajasthan). Data was analyzed using Microsoft Office excel 2007 & using past4.13 software.

Data Analysis

To evaluate species diversity across the study sites, alpha, beta, and gamma diversity indices were calculated. Alpha diversity was analysed to evaluate the diversity within each study site. Different indices (Shannon-Wiener, Simpson's Index of diversity, Margalef's index and Pieolu's index) were computed for each site to evaluate species richness, evenness and distribution pattern. Among the study sites the variation in species composition was assessed through Beta diversity. Gamma diversity, indicating total species diversity across all sites, was determined by counting all observed species.

1. Shannon–Wiener Diversity Index (H')

It is alpha diversity index. It provides a measure of species diversity by considering both species richness and species evenness. Shannon–Wiener diversity index (Shannon, 1948) is calculated as-

$$H' = -\sum (p_i \ln(p_i))$$

Where-

$$P_i = n_i / N$$

- n_i = number of individuals of i th species
- N = total number of all individuals in the sample
- \ln = logarithm to base e
- Low H' → low diversity and dominance of few species
- High H' → high diversity with balanced distribution of species

2- Simpson's Index (D)

Simpson's index is another measure of biodiversity. It denotes the alpha diversity of the selected area. It reflects both species richness and evenness. The Simpson's Index (Simpson, 1949) is calculated as-

$$D = \frac{\sum ni (ni-1)}{N (N -1)}$$

Where-

- N = total number of individuals
- ni = number of individuals of ith species
- The value of 'D' ranges from 0 to 1. Higher value of 'D' represents lower diversity
- D= 0 represents infinite diversity
- D=1 represents no diversity/ very low diversity

3- Simpson Index of Diversity (1 - D)-

The Simpson Index of Diversity (1 - D) is a measure of diversity that takes into account both richness (the number of species) and evenness. It reflects the probability that two individuals randomly selected from a sample will belong to different species.

$$1-D = 1 - \frac{\sum ni (ni-1)}{N (N -1)}$$

- ni = number of individuals of species *i*
- N = total number of individuals of all species
- D = Simpson's Index (dominance index; probability two individuals are the same species)
- 1-D = Simpson's Diversity Index
- Values range from 0 to 1
- Closer to 1 = high diversity
- Closer to 0 = low diversity
- If one species dominates, the index will be low.
- If many species are equally present, the index will be high.

4- Margalef's Index (D_{Mg})

This index is also an alpha diversity index and used as a simple measure of species richness (Magurran, 1988).

$$D_{Mg} = (S - 1) / \ln(N)$$

- D_{Mg} = Margalef's diversity index
- S = total number of species
- N = total number of individuals in the sample
- ln = natural logarithm
- Low D_{Mg} value → low species richness
- High D_{Mg} value → high species richness

5- Pielou's Evenness Index (J')

Pielou's index is an alpha diversity index that measures how evenly species are distributed in a community (Pielou, 1969).

$$J' = H' / \ln(S)$$

- H' = Shannon – Wiener diversity index
- S = total number of species in the sample
- Low J' → close to 0 (uneven distribution, few species dominate).
- High J' → close to 1 (high evenness, individuals distributed almost equally among species).

6- Relative Abundance

The Relative Abundance of a species shows how common a species is compared to all species in a community.

$$\text{Relative Abundance (\%)} = \frac{\text{Number of individuals of a specific species}}{\text{Total number of individuals of all species}} \times 100$$

6- Jaccard's Index (J)- The Jaccard Similarity Index measures the proportion of shared species between two communities relative to the total number of species found in both. Similarity between two communities can be calculated as-

$$J = S_c / S_a + S_b + S_c$$

Where, S_a and S_b are the number of species unique to Site a and Site b respectively, and S_c is the number of species common to both the sites.

Dissimilarity between two communities can be calculated as-

$$\text{Jaccard Dissimilarity Index (D}_j\text{)} = 1 - \text{Jaccard Similarity Index (J)}$$

CHAPTER-4
RESULT AND DISCUSSION

CHAPTER-4

RESULT AND DISCUSSION

In the present investigation biodiversity study of butterflies was carried out in semi-arid zone, Kota and its adjoining villages, Rajasthan, India. Data was recorded from four different sites- site 1 (managed garden spaces urban), site 2 (habitat situated near water body), site 3 (agricultural field used for crop production) and site 4 (natural landscape with least disturbance). Study was carried out for three years (March 2022- February 2025). A total of 5198 individuals of butterflies were recorded from the study sites representing 38 species belonging to 27 genera and 5 families.

(A) Distribution of Species Among Families

In the year 2022-2023, total of 1,612 individuals were recorded, followed by 1,692 individuals in the second year (2023-2024) and 1,894 individuals in the year 2024-2025, representing 38 species belonging to 27 genera and 5 families of superfamily Papilionoidea . Throughout the study period, the number of species at site 4 (Kolipura- 38 species), at site 2 (Abheda- 11 species) and at site 3 (Bhopatpura- 8 species) remained consistent. Whereas at site 1 (C.V garden) 19 species were reported in the year 2022-2023 and for the subsequent two years the species count remained unchanged (25 species).

During the study period, in terms of species the least dominant family was HesperIIDae at site 1 and site 4. Similar observations were reported from the Gulmarg region of Jammu & Kashmir, where HesperIIDae was represented by only one genus and one species (Dar et al., 2022). In other regions as well, HesperIIDae consistently ranked as the least dominant family, such as in the Udzungwa Mountains, Tanzania (Nyundo et al., 2022), Xinjiang, China (Li et al., 2020), and Buxa Tiger Reserve, India (Roy et al., 2024). Studies from Dachigam National Park, J&K (Dar & Khan, 2021), and the Garo Hills, Assam (Sarma et al., 2016), also confirmed that HesperIIDae formed the least represented family in terms of species diversity.

At site 2 (Abheda) the least dominant family in terms of species was Lycaenidae (18.18%) followed by Pieridae (27.27%) in the three years. While at site 3, over the three years, Lycaenidae (25%) and Pieridae (25%) showed the equal contribution in terms of species composition.

Over the span of three years of study, the most dominant family in terms of species composition was Nymphalidae family. Similar results were also reported from Gurukula Kangri University campus, where Nymphalidae remained the most dominant family during consecutive years of observation (Kumar et al., 2017).

(a) Species Composition of Butterfly Families During the Year 2022-2023

At site 1 in the year 2022-2023, among the recorded butterfly families, Nymphalidae contributed the highest percentage of species composition (36.8%), followed by Pieridae and Lycaenidae (21% each) and Papilionidae (15.78%). Family Hesperidae contributed the least (5.26%) to the species composition at site 1. The high dominance of family Nymphalidae in the study site suggests that this family had strong adaptation to the existing environmental settings. Low percentage of species of family Hesperidae suggest that habitat of present site do not favour its species.

Across the site 2, family Nymphalidae was the most speciose with species composition 54.54%, followed by Pieridae (27.27%) and Lycaenidae (18.18%). Family Papilionidae & Hesperidae were completely absent at site 2. The absence of these two families at this site suggests that they have specific habitat preference which is not available at this site.

In the study site 3, across the observed butterfly families, Nymphalidae contributed the highest percentage of species composition (50%), family Pieridae and Lycaenidae showed the similar percentage of species composition (25%). Family Papilionidae & Hesperidae were completely absent at site 3. Absence of these two families from site 3 suggests the lack of resources for survival and reproduction. It also indicates that the habitat at site 3 do not support their ecological requirements.

Within the site 4, family Nymphalidae contributed the highest percentage of species composition (42.10%), followed by Pieridae (23.68%) and Lycaenidae (18.42%).

Papilionidae(10.52%) ranked next in terms of species composition. Hesperidae contributed the least percentage of species (5.26%) which is similar to the site 1. Highest dominance of family Nymphalidae suggests that this family reflects its strong adaptation to the local habitat conditions.

This pattern suggests that butterflies of Nymphalidae family are generalist whereas family Hesperidae shows the sensitivity to the habitat quality.

(b) Species Composition of Butterfly Families During the Year 2023-2024

In the year 2023-2024 at site 1, among the recorded butterfly families, Nymphalidae contributed the highest percentage of species composition (40%), followed by Lycaenidae (24%). Family Papilionidae and Pieridae (16%) showed similar percentage of species composition. Hesperidae contributed the least percentage of species (4%). The dominance of Nymphalidae can be due to polyphagous habit that helped them to live in all habitats (Sreekumar and Balakrishnan, 2001b). The reason for the lowest species richness and abundance showed by Hesperidae family may be their flight period (early morning hours at dawn and dusk, Kehimkar, 2008) and narrow host plant range and absence of suitable habitat.

Throughout the year 2023-2024 at site 2, site 3 and site 4, the percentage species composition of all the families was similar to that observed during the first year (2022-2023). This consistency reflects that the ecosystem at site 2, 3 and 4 is stable.

(c) Species Composition of Butterfly Families in the Year 2024-2025

Across the period 2024-2025, at all the sites the percentage of species composition of all the families was similar to that observed in the year 2023-2024. There was no variation in the family wise species composition during this period. It means the area has reached stability, supporting the same set of species without new ones coming in or old ones disappearing. This result is supported by (Evans et al., 2022) no change in family-level species composition was observed, suggesting that the butterfly community had reached a state of stability, maintaining the same set of species without any new arrivals or extinctions over time.

Table 1: Family wise percentage composition of species at all the sites

S.No	Families	Site 1			Site 2			Site 3			Site 4		
		2022-23	2023-24	2024-25	2022-23	2023-24	2024-25	2022-23	2023-24	2024-25	2022-23	2023-24	2024-25
1	Papilionidae	15.78%	16%	16%	-	-	-	-	-	-	10.52%	10.52%	10.52%
2	Pieridae	21%	16%	16%	27.27%	27.27%	27.27%	25%	25%	25%	23.68%	23.68%	23.68%
3	Lycaenidae	21%	24%	24%	18.18%	18.18%	18.18%	25%	25%	25%	18.42%	18.42%	18.42%
4	Nymphalidae	36.8%	40%	40%	54.54%	54.54%	54.54%	50%	50%	50%	42.10%	42.10%	42.10%
5	Hesperiidae	5.26%	4%	4%	-	-	-	-	-	-	5.26%	5.26%	5.26%

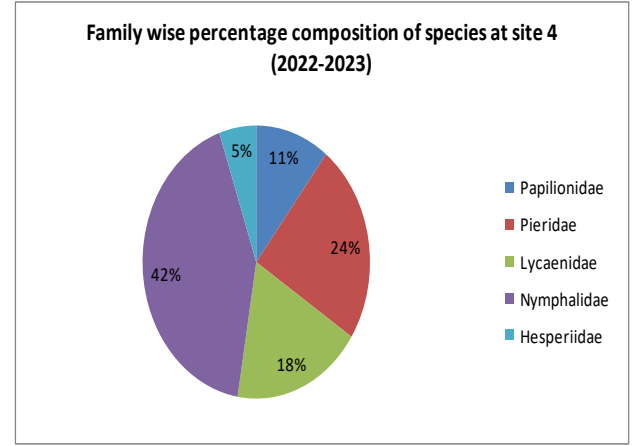
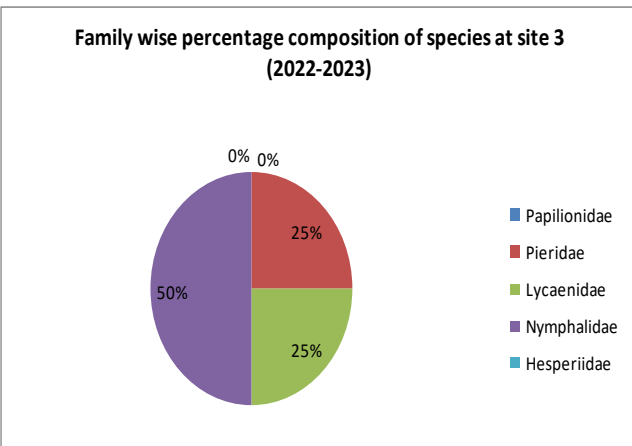
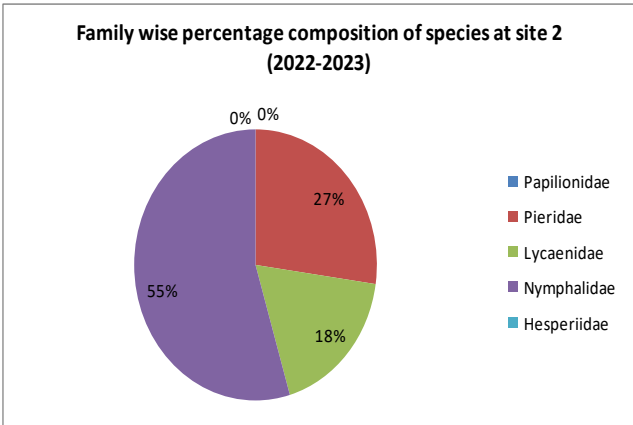
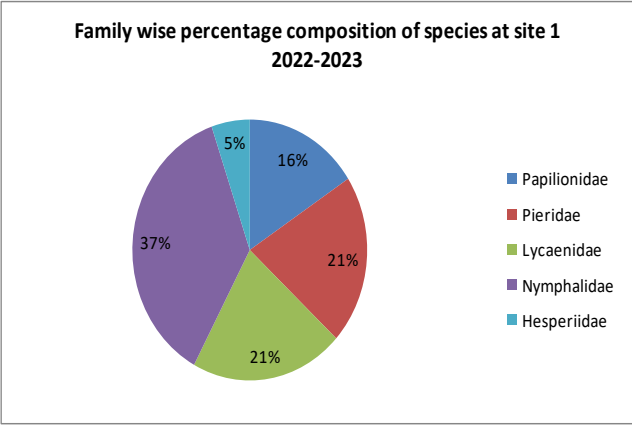


Fig 2: Graph of family wise percentage composition of species in the year 2022-2023.

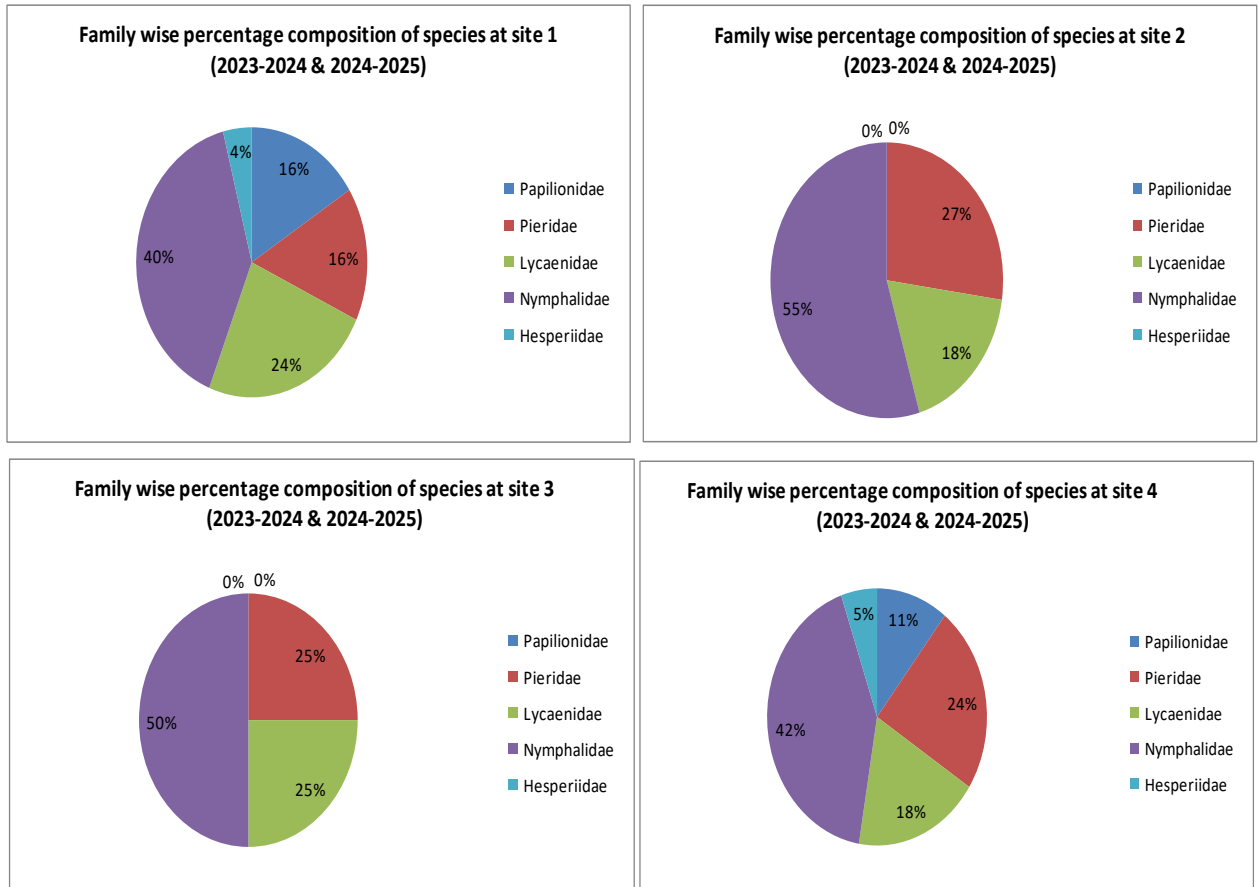


Fig 3: Family wise percentage composition of species in the year 2023-2024 & 2024-2025.

Over the span of three years, the same number of families was recorded at each sampling site. During the study period, the number of species does not changed with time across different sites, apart from site 1 where the higher number of species were reported in the rest two years as compared to year 2022-2023. At site 1 the increased number of species was observed in the year 2023-2024. This rise may be due to improved vegetation conditions, including the availability of host and nectar plants preferred by butterflies and reduction in human disturbances during this period likely created more favorable habitat conditions, which in turn supported higher species richness.

Throughout the study of three years, all the sites exhibited a progressive rise in the number of individuals. Only site 2 showed deviation from this trend where a reduction occurred in the 2023-2024 year but was followed by a subsequent recovery in the 2024-2025 year. The number of individuals at site 2 in the year 2023-2024 decreased, as the natural vegetation of the area had been largely destroyed by increasing anthropogenic activities. Similar results reported by (López-Vázquez et al., 2024) the number of individual butterflies declined markedly due to indiscriminate cutting of plants and trees, as well as the large-scale destruction of natural vegetation caused by increasing anthropogenic activities. Such disturbances not only reduce host plant availability but also degrade habitat structure and nectar resources, leading to a significant decrease in butterfly richness and disruption of butterfly–plant interactions.

Table 2: Number of families, species and individuals during the study period

Sites	Number of Families			Number of species			Number of individuals		
	Year 2022-2023	Year 2023-2024	Year 2024-2025	Year 2022-2023	Year 2023-2024	Year 2024-2025	Year 2022-2023	Year 2023-2024	Year 2024-2025
1	5	5	5	19	25	25	205	365	397
2	3	3	3	11	11	11	191	86	110
3	3	3	3	8	8	8	30	37	61
4	5	5	5	38	38	38	1186	1204	1326

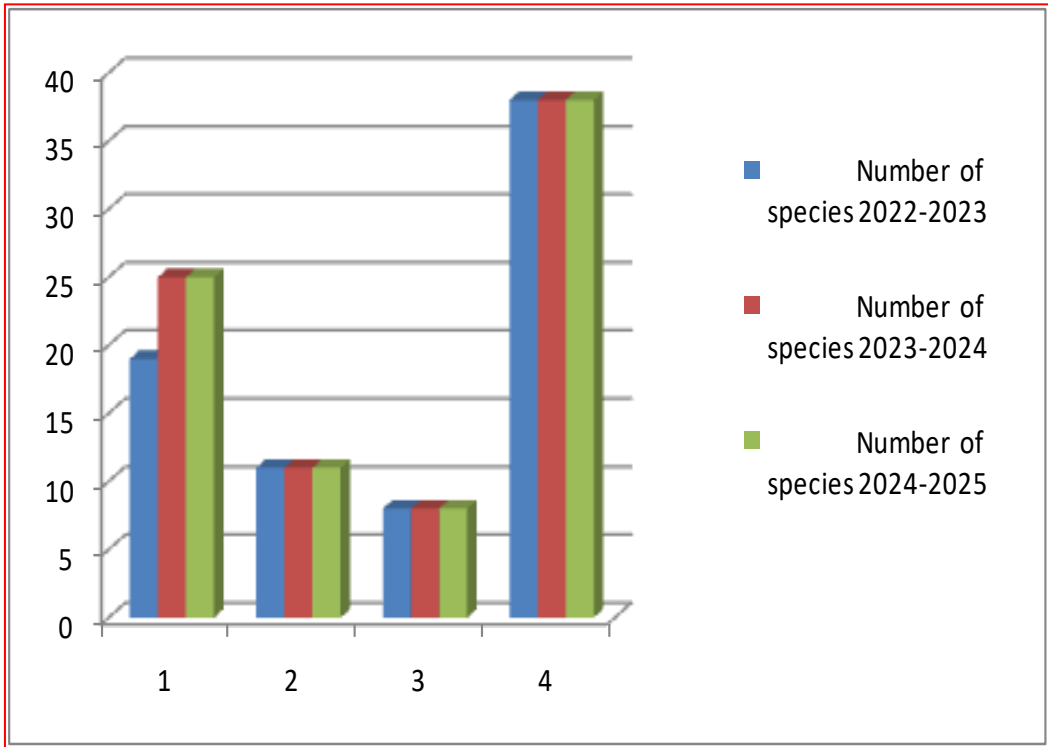


Fig 4a: (a) Number of species of butterflies present at all sites across the three years (X-Axis= Sites, Y-Axis= Number of species).

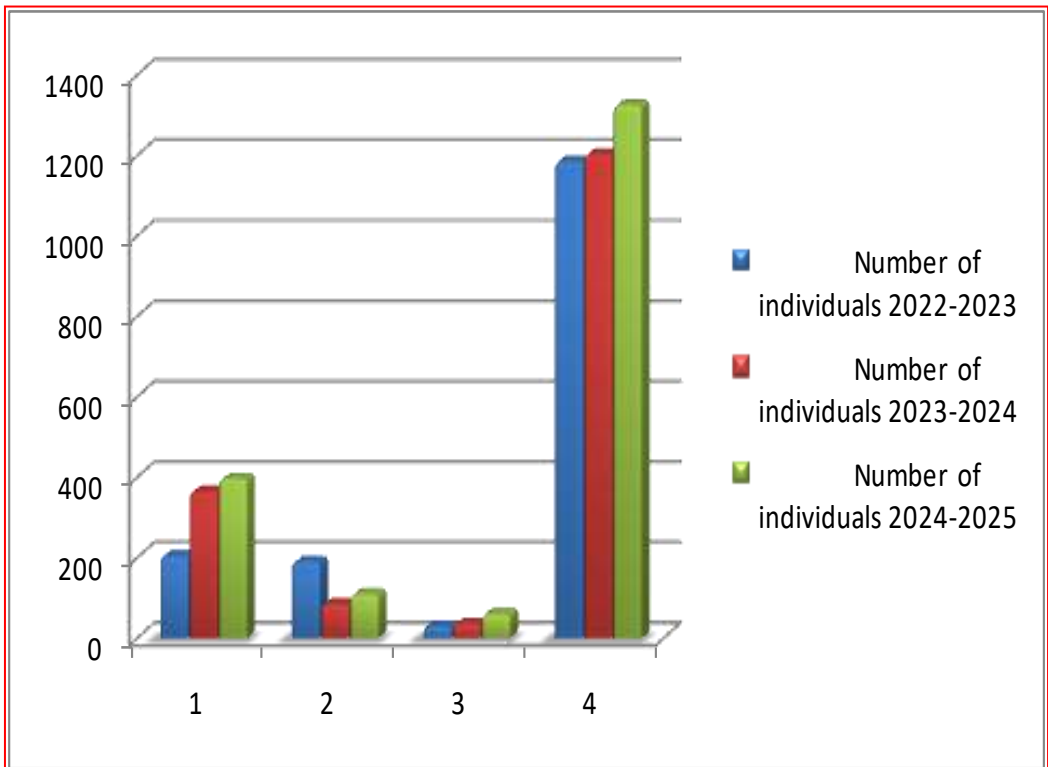


Fig 4b: (b) Number of individuals of butterflies present at all the sites across the three years. (X-Axis= Sites, Y- Axis= Number of individuals).

Table 3: Checklist of butterfly species recorded during the study period

S.No.	Common Name	Scientific Name	Family
1	Common Jay	<i>Graphium doson</i>	Papilionidae
2	Common Rose Swallowtail	<i>Pachliopta aristolochiae</i>	Papilionidae
3	Common Mormon Swallowtail	<i>Papilio polytes</i>	Papilionidae
4	Lime Swallowtail	<i>Papilio demoleus</i>	Papilionidae
5	Mottled Emigrant	<i>Catopsilia pyranthe</i>	Pieridae
6	Spotless Grass Yellow	<i>Eurema laeta</i>	Pieridae
7	Common Grass Yellow	<i>Eurema hecabe</i>	Pieridae
8	Striped Albatross	<i>Appias libythea</i>	Pieridae
9	Common Gull	<i>Cepora nerissa</i>	Pieridae
10	Pioneer White	<i>Belenois aurota</i>	Pieridae
11	Common Jezebel	<i>Delias eucharis</i>	Pieridae
12	White Orange Tip	<i>Ixias Marianne</i>	Pieridae
13	Common Emigrant	<i>Catopsilia Pomona</i>	Pieridae
14	Grass Jewel	<i>Chilades trochylus</i>	Lycaenidae
15	Dark Grass Blue	<i>Zizeeria karsandra</i>	Lycaenidae
16	Striped Pierrot	<i>Tarucus nara</i>	Lycaenidae
17	Pale Grass Blue	<i>Pseudozizeeria maha</i>	Lycaenidae
18	Forget-me-not	<i>Catochrysops Strabo</i>	Lycaenidae
19	Zebra Blue	<i>Leptotes plinius</i>	Lycaenidae
20	Lime Blue	<i>Chilades lajus</i>	Lycaenidae
21	Blue Pansy	<i>Junonia orithya</i>	Nymphalidae
22	Plain Tiger	<i>Danaus chrysippus</i>	Nymphalidae
23	Lemon Pansy	<i>Junonia lemonias</i>	Nymphalidae
24	Tawny Coster	<i>Acraea Terpsichore</i>	Nymphalidae
25	Common Tiger Butterfly	<i>Danaus genutia</i>	Nymphalidae
26	Grey Pansy	<i>Junonia atlites</i>	Nymphalidae
27	Danaid Eggfly	<i>Hypolimnas misippus</i>	Nymphalidae
28	Chocolate Pansy	<i>Junonia iphita</i>	Nymphalidae
29	Common Castor Butterfly	<i>Ariadne merione</i>	Nymphalidae
30	Angled Castor	<i>Ariadne ariadne</i>	Nymphalidae
31	Common Evening Brown	<i>Melanitis leda</i>	Nymphalidae
32	Peacock Pansy	<i>Junonia almanac</i>	Nymphalidae
33	Blue Tiger	<i>Tirumala limniace</i>	Nymphalidae
34	Common Leopard	<i>Phalanta phalantha</i>	Nymphalidae
35	Common Crow	<i>Euploea core</i>	Nymphalidae
36	Great Eggfly	<i>Hypolimnas bolina</i>	Nymphalidae
37	Rice Swift	<i>Borbo cinnara</i>	Hesperiidae
38	Indian Palm Bob	<i>Suastus gremius</i>	Hesperiidae

(B) Alpha Diversity

Alpha diversity expresses the local diversity and it offers an assessment of number of species present and evenness within the site.

(a) Species Richness of Butterflies Across Study Sites

Altogether 38 species were documented from all the sites. Throughout the study period similar number of species were reported at site 4 (Kolipura- 38 species), site 2 (Abheda- 11 species) and site 3 (Bhopatpura- 8 species). Whereas at site 1 (C.V garden) 19 species were reported in the year 2022-2023 and for the subsequent two years the species count remained unchanged (25 species). This indicates that natural area supports the maximum number of species as compared to the other three sites. Undisturbed natural areas generally harbor more butterfly species than disturbed sites, as stable habitats provide richer floral resources and host plants needed for their survival (Kunte, 1997; Thomas, 2005; Bonebrake et al., 2010).

Margalef's index is a measure of species richness, considering the number of species and total individuals of a community.

Over the two years (2022-2023, 2023-2024) increase in Margalef's index (Table-4) at site 1 was observed which indicates a notable improvement in the species richness, this is due to the habitat restoration and improved conditions in the habitat. Recreated habitats such as butterfly gardens have been shown to enhance butterfly diversity. A case study at Thenmala, Kerala, reported that restored habitats not only increased butterfly abundance and species richness but also supported rare and endemic swallowtails (Mathew & Anto, 2007).

While in the year 2024-2025 slight decrease in Margalef's index indicates that species richness relative to the sample size has reduced. This suggests that although the species count did not change but distribution of individuals across species became less even, leading to a slight reduction in the richness index. The steadiness in species richness in the year 2024-2025, reflects taxonomic stability of the butterfly community at site 1. Yet the increased number of individuals

advocate the improved habitat quality and resource availability resulting in population growth of the resident species.

At site 2, in the first two successive years (2022-2023, 2023-2024), Margalef's index showed a slight increase, but in the following year (2024-2025), it exhibited a minor decline. Since the total number of species remained constant, this pattern suggests that the richness value was influenced more by changes in the number of individuals rather than by an actual change in species count. Such fluctuations indicate subtle shifts in community structure or ecological conditions even without variation in the number of species present. So the site is stable in terms of species number but not getting richer despite the increased number of individuals.

At site 2 in the year 2023-2024, the observed decreased number of individuals following indiscriminate plant cutting, indicates that habitat degradation had a strong impact on the community. Vegetation loss diminishes resource availability and ecological niches, which in turn reduces the abundance of organisms and weakens overall ecosystem resilience.

In the year 2024-2025, the number of individuals increased again at site 2, which indicates a positive ecological response. This rise reflects the recovery of habitat conditions, improved resource availability and favourable climatic factors that supported population growth. Such a trend suggests that the ecosystem is regaining its capacity to sustain higher abundance levels.

During the first two years (2022-2023, 2023-2024) at site 3, Margalef's index showed only minor decline, as the number of individuals increased slightly. In the 2024-2025 year a more pronounced decline was observed in Margalef's index as the marked number of individuals increased. Since the total number of species remained unchanged, this reduction in the Margalef's index is likely linked to changes in individual abundance. The result suggests that as the species variety was stable, but the population of individuals was increased which reflects that community composition was constant so the habitat supports the same species over the time. Such a pattern indicates the quantitative expansion rather than the qualitative enrichment.

At site 4 species richness is still the highest and stable, which is indicated by minimal change in the Margalef's index value over the span of three years. So making the habitat an ecological hotspot for biodiversity. The steadiness in Margalef's index across the study period reflects that at the site 4 the species richness remained stable. This stability suggests that the ecological influences and habitat conditions were largely similar and constant over time, thereby reflecting the ecological persistence and stability of the prevailing community structure.

(b) Species Evenness of Butterflies Across Study Sites

Species evenness refers to how evenly individuals are distributed among the species in a community. When a single species dominates the community and rest of the species are rare, the community exhibit low evenness. High evenness is shown by community when individuals are uniformly spread across different species.

Pielou's Index (J) expresses the species evenness. At site 1 and site 2, a significant increase in Pielou's index value was observed in the next two consecutive years (2023-2024, 2024-2025), as compared to the first year, which indicates that the community structure is becoming much more balanced than the year 2022-2023(Table-4).

Pielou's index value of site 3 & 4 in all three years was very close to 1, which reflects that throughout the study period distribution of individuals was uniform across the species (Table-4).

Throughout the study of three years the highest evenness was observed at site 4 (Table-4), which indicates that the species are distributed more equally at this site, no single species is dominating in this habitat. Thus ecosystem at site 4 is stable and healthy with minimal competition issues. At natural sites, butterfly communities usually show higher evenness because resources and microclimatic conditions are more stable, which allows different species to share the habitat more evenly (Kunte, 1997; Sharma et al., 2023; Neha & Kumar, 2025).

Similarly site 3 also has high evenness in the study of all three years indicating good species balance in the ecosystem though slightly lower than site 4. However site 1 and site 2 have moderate evenness with some species being more dominant at these sites. This in turn reduces the evenness of the ecosystem. Such results are due to habitat disturbance and non-availability of host and nectar plants for other species. Lower evenness in the ecosystem contributes to the lower biodiversity, as dominant species displace the other species.

The documented variation in species evenness indicates the differences in habitat stability and resources distribution across the sites. Lower evenness at site 1 & site 2 suggests that only few species represented majority of the individuals, this pattern happens in disturbed or resource poor habitats. Whereas the high evenness at site 3 & site 4, indicates an evenly structured community, where none of the species is dominant, which is reflecting a least disturbed or steady ecological situation.

(c) Diversity Assessment of Study Sites Using Shannon-Weiner Index (H) and Simpson Index of Diversity (1-D)

The Shannon-Weiner Index varied between 1.883 to 3.506 in the study sites. The highest value of Shannon-Weiner Index was reported at site 4 and the lowest value was recorded at site 2. The Simpson index of diversity varied between 0.824 to 0.968 in the study sites. The highest value of Simpson index of diversity was reported at site 4 and the lowest value was recorded at site 2.

A relatively higher Shannon or Simpson index of butterfly diversity at site 4 in all the three years of study signifies that the butterfly community at this site is composed of a greater variety of species with a more even distribution of individuals. Such a pattern reflects that the habitat at site 4 offers suitable ecological conditions, including resource availability and microclimatic stability, which allow multiple butterfly species to coexist. Therefore, if a particular site consistently records the highest diversity indices across different years, it can be interpreted as a key habitat that sustains rich and balanced butterfly populations and contributes significantly to the overall conservation value of the landscape.

The findings of this study was further supported by Hill et al. (1995); Brown (1997), Akwashiki et al. (2007) and Bonebrake et al. (2010), they reported higher abundance of butterfly species in less disturbed habitats. Natural areas usually record the highest Shannon and Simpson diversity index values, as undisturbed habitats support richer and more evenly distributed butterfly communities compared to disturbed sites (Kunte, 1997; Sharma et al., 2023; Dawar et al., 2024). In the Undisturbed site of present investigation, the higher diversity and abundance was observed, which may be due to the diverse availability of nectar and host plants for butterflies. This result favours the statement of Sreekumar and Balakrishnan (2001a), they suggested that prevalence of butterfly species at a particular habitat depends on a wide range of factors, of which the availability of the food is the most important.

It was observed in the survey data of the first two years that there is slight drop in Shannon-Weiner index and Simpson index of diversity at site 4 which suggests that high diversity is still maintained at site 4 but experiencing small changes in species distribution. Other possible cause for these minor changes is the increasing anthropogenic activity in the study area. So the monitoring of this natural area should be done to ensure the ecosystem stability. Where as in the year 2024-2025, the value of the Shannon-Wiener index again increased, while the number of species remained consistent with the 2023-2024 year. This reflects a change in evenness without any significant change in species richness.

Simpson index of diversity at site 4 remained constant in the year 2023-2024 & 2024-2025, while the total number of species did not change. This indicates that the distribution of species have remained consistent, reflecting a stable community structure.

Second highest Shannon-Weiner index & Simpson index of diversity was observed at site 1, across all three years, indicating moderate diversity and reasonably diverse community having rich species distribution. Relatively low Shannon-Weiner index and Simpson index of diversity was reported at site 2 and site 3 in all three years of study, which indicates low diversity with fewer species being dominant.

When comparing the first two years (2022-2023 & 2023-2024) the Shannon-Weiner and Simpson index of diversity showed an increase in 2023-2024 at site 1 which indicates the higher species diversity as compared to the last year, which may be due to improved habitat conditions, better resource availability for the butterflies at site 1. Similarly when comparing the data of year 2023–24 and 2024–25, an increase in the Shannon-Weiner and Simpson index of diversity was also observed in 2024–25 at site 1, although the total number of species remained unchanged. This suggests that the community structure became more balanced with a more even distribution of individuals among the species in the course of time, rather than being dominated by a few species.

Throughout the study of three years at site 2 and site 3 there is slight increase in Shannon-Weiner index and Simpson index of diversity (Table-4), although the number of species remained constant. This reflects improved species evenness, with individuals being distributed more uniformly across species.

In the present study high Shannon-Weiner index of site 4 and site 1 indicates that these two sites are having stable and healthy ecosystem with good resource availability. Lower Shannon-Weiner index and Simpson index of diversity of site 2 and site 3 in the present investigation indicates the environmental disturbances and low resource availability.

Table 4: Comparison of butterfly diversity indices at site 1, site 2, site 3 and site 4

Sites	Shannon-Weiner Index (H')			Simpson index of diversity (1-D)			Pielou's Index (J')			Margalef's Index (D _{Mg})		
	2022-23	2023-24	2024-25	2022-23	2023-24	2024-25	2022-23	2023-24	2024-25	2022-23	2023-24	2024-25
1	2.288	2.924	2.945	0.865	0.938	0.939	0.777	0.908	0.915	3.381	4.068	4.011
2	1.883	2.056	2.170	0.824	0.858	0.872	0.785	0.857	0.905	1.904	2.245	2.127
3	1.905	1.938	2.009	0.863	0.864	0.872	0.916	0.932	0.966	2.058	1.939	1.703
4	3.506	3.458	3.483	0.968	0.966	0.966	0.963	0.950	0.957	5.227	5.216	5.146

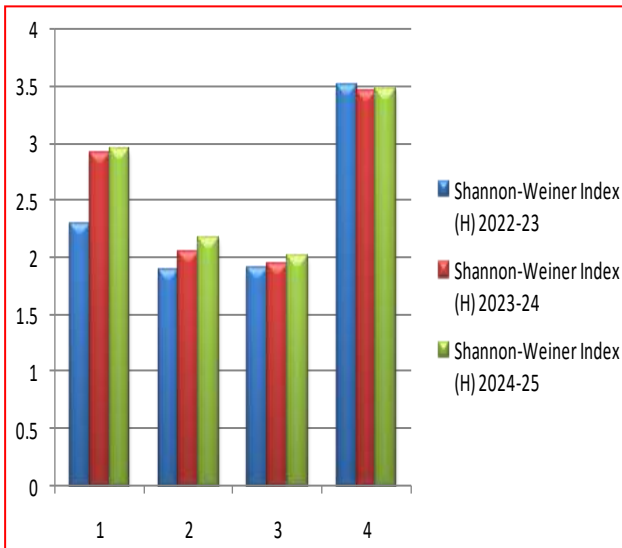


Fig 5a: Shannon-Weiner Index (H) in the study area across three years.
(x-axis = Sites, y-axis = Shannon-Weiner Index)

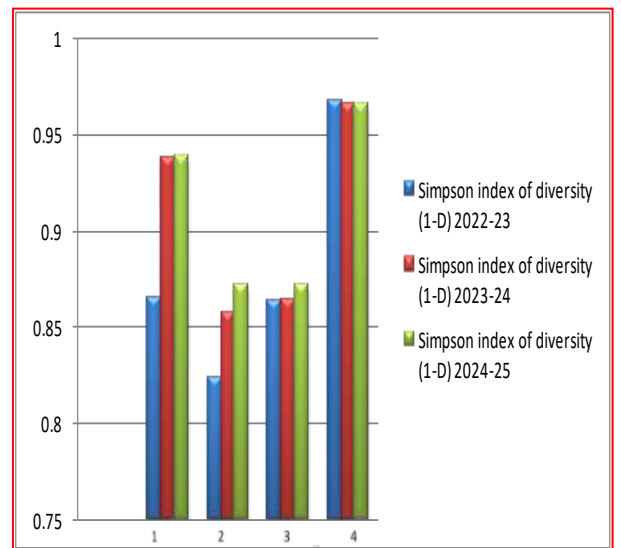


Fig 5b: Simpson index of diversity (1-D) in the study area across three years.
(x-axis = Sites, y-axis = Simpson index of Diversity)

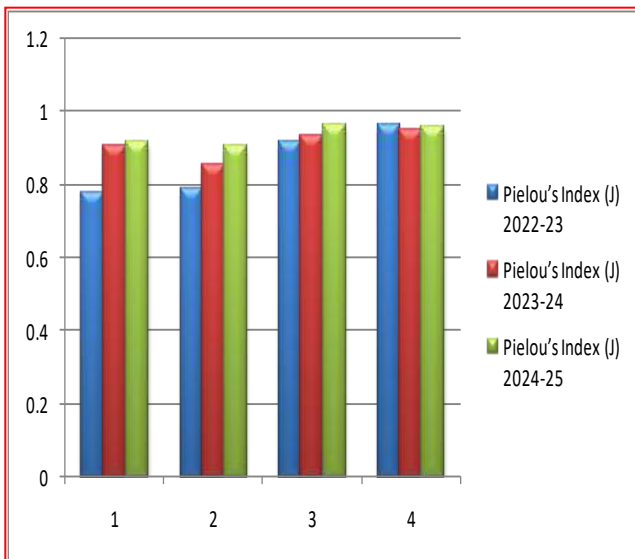


Fig 6a: Pielou's Index (J) in the study area across three years.
(x-axis = Sites, y-axis = Pielou's Index)

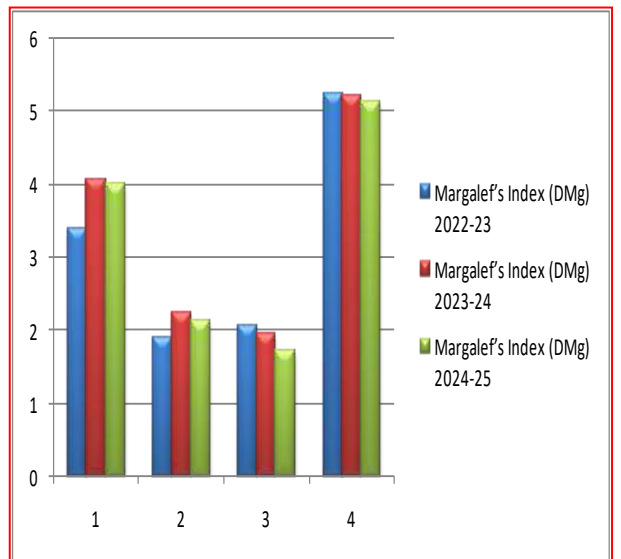


Fig 6b: Margalef's Index (D_{Mg}) in the study area across three years.
(x-axis = Sites, y-axis = Margalef's Index)

(d) Relative abundance

Relative abundance represents the percentage of individuals of one species relative to the total number of individuals of all the species in an area. It indicates the degree to which a species is abundant or scarce in comparison to other species within the ecosystem.

In the year 2022-2023, total 205 individuals from 19 species were recorded at site 1. The most abundant species at site 1 was spotless grass yellow and plain tiger butterfly (20.97% each). The least abundant species in the year 2022-2023 were common rose swallowtail, striped pierrot, striped albatross and rice swift (0.48% each). At site 1, four abundant species constituted 70% of the total individuals whereas the remaining 15 species collectively share 30% of the community composition.

Altogether 365 individuals were recorded at site 1 in the year 2023-2024. The most abundant species at site 1 was common grass yellow (11.23%) and the least abundant species was lime swallowtail (0.27%). Observation from site 1 indicated that 20 species constituted 51% of total individuals while 5 species contributed 49% to the community structure.

Overall 397 individuals were recorded at site 1 in the year 2024-2025. Common grass yellow was the most abundant species representing 12.09% of total individuals whereas the least abundant species was common mormon swallowtail (0.50%). In this year five species represented 45.82% of the butterfly community and 54.18% individuals represented the 20 species.

At site 1 in the first year the community was dominated by spotless grass yellow and plain tiger butterfly whereas during the next couple of years common grass yellow appeared as the most abundant species. This shift in species dominance suggests the temporal fluctuation in community composition. This shift may be due to the changes in habitat condition, availability of resources. Such trend suggests that the community is dynamic and responds to the environmental influences on species abundance.

Table 5: Relative abundance of butterfly species over three years at site 1

Family	Species	2022-2023	2023-2024	2024-2025
Papilionidae (4)	Common jay	1.46%	1.64%	0.75%
	Common rose swallowtail	0.48%	0.82%	1.00%
	Common mormon swallowtail	1.46%	0.82%	0.50%
	Lime swallowtail	Nil	0.27%	0.75%
Pieridae (4)	Mottled emigrant	4.39%	4.38%	3.52%
	Spotless grass yellow	20.97%	9.31%	9.06%
	Common grass yellow	11.21%	11.23%	12.09%
	Striped albatross	0.48%	7.12%	6.80%
Lycaenidae (6)	Grass jewel	5.36%	5.47%	4.78%
	Dark grass blue	0.97%	1.91%	2.01%
	Striped pierrot	0.48%	2.19%	1.51%
	Pale grass blue	1.46%	3.83%	3.02%
	Forget-me-not	Nil	2.46%	2.51%
	Zebra blue	Nil	1.36%	1.00%
Nymphalidae (10)	Blue pansy	1.46%	3.28%	3.27%
	Plain tiger butterfly	20.97%	10.68%	9.06%
	Lemon pansy	3.41%	4.10%	5.28%
	Tawny coster	3.41%	4.10%	5.03%
	Common tiger butterfly	17.07%	10.41%	8.81%
	Grey pansy	1.46%	2.73%	5.03%
	Danaid eggfly	2.92%	2.73%	3.77%
	Great eggfly	Nil	2.46%	2.77%
	Common castor	Nil	3.56%	3.77%
	Chocolate pansy	Nil	2.46%	2.77%
Hesperiidae (1)	Rice swift	0.48%	0.54%	1.00%

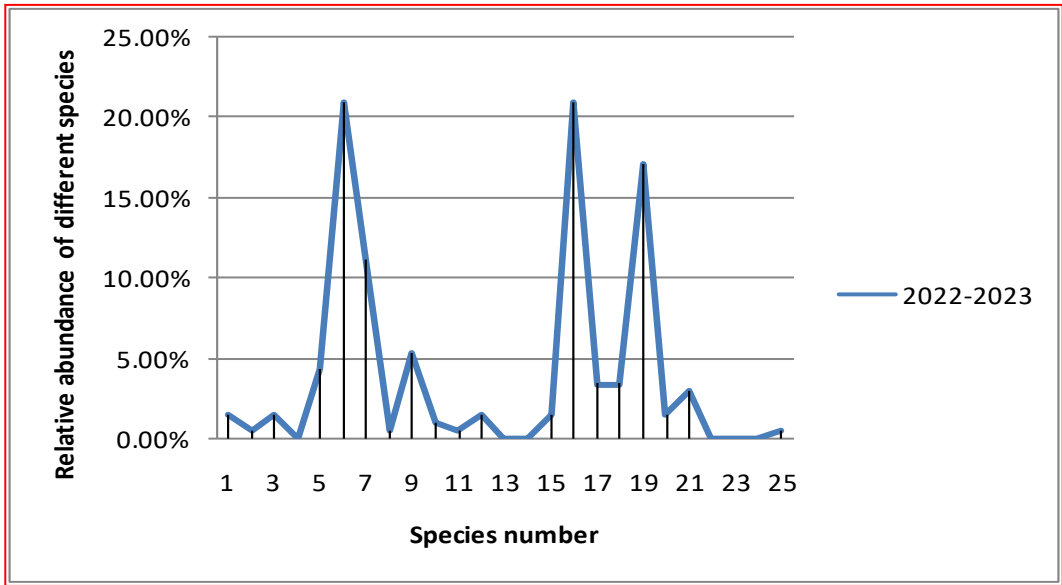


Fig 7a: Variation in relative abundance of different species at site 1 during the year 2022-2023.

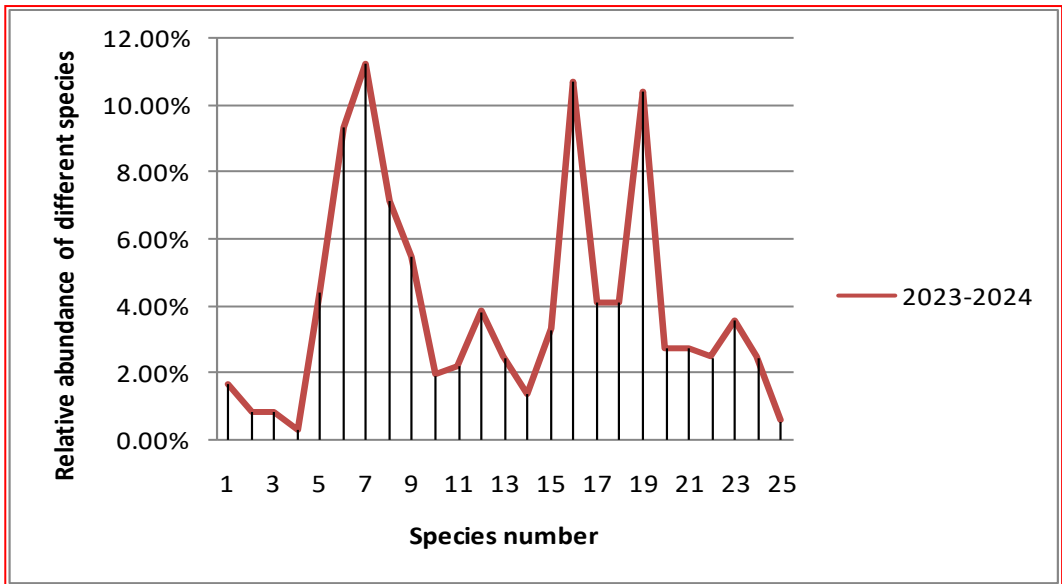


Fig 7b: Variation in relative abundance of different species at site 1 during the year 2023-2024.

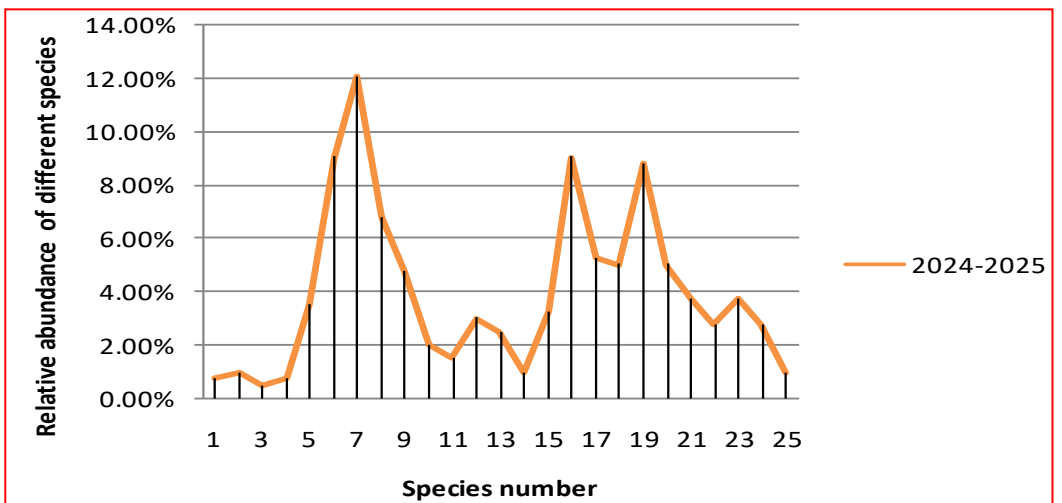


Fig 7c: variation in relative abundance of different species at site 1 during the year 2024-2025.

The steep decline of the curve suggests that a small number of species dominated the community, while others were relatively rare, indicating moderate evenness at site 1. Thus, this site, characterized by high richness but only moderate evenness, reflects a diverse community where dominance is concentrated in a few species.

In the year 2022-2023, at site 2 total 191 individuals were recorded. Most abundant species at site 2 was pale grass blue (26.17%) and the least abundant species were blue pansy and danaid eggfly (0.52% each). This time five species represented the maximum contribution (90.02%) to the community structure, remaining 6 species contributed 9.98% of the total individuals.

Altogether 86 individuals were recorded at site 2 in the year 2023-2024. The remarkable observed decline in the number of individuals this year was due to the indiscriminate cutting of plants. Common tiger butterfly was the most abundant species at site 2 and the least abundant species was blue pansy (1.16%). In the present year five abundant species constituted 81.37% of the total individuals whereas the remaining 6 species collectively shared 18.63% of the community composition.

Overall 110 individuals were recorded at site 2 in the year 2024-2025. Common tiger butterfly was the most abundant species representing 22.72% of total individuals whereas the least abundant species were mottled emigrant, grass jewel, blue pansy, lemon pansy and danaid eggfly (3.63% each). Observation from site 2 indicated that 6 species constituted 81.8% of total individuals while 5 species contributed 18.2% to the community structure.

During the initial year of observation at site 2 pale grass blue showed peak abundance however in the subsequent two years common tiger butterfly became the most abundant species. The observed shifts in species dominance and distribution patterns suggest that species exhibit flexibility in response to ecological pressures such as climatic variations, resource availability, and habitat changes. These findings indicate that community structure is not fixed but dynamic. This dynamism strengthens the ecosystem's ability to absorb disturbances while still maintaining the overall integrity of the community.

Table 6: Relative abundance of butterfly species over three years at site 2

Families	Species	2022-2023	2023-2024	2024-2025
Pieridae (3)	Mottled emigrant	2.09%	2.32%	3.63%
	Spotless grass yellow	13.61%	16.27%	18.18%
	Common grass yellow	9.94%	12.79%	9.09%
Lycaenidae (2)	Grass jewel	1.57%	2.32%	3.63%
	Pale grass blue	26.17%	19.76%	14.54%
Nymphalidae (6)	Blue pansy	0.52%	1.16%	3.63%
	Plain tiger butterfly	21.98%	9.30%	9.09%
	Lemon pansy	3.66%	3.48%	3.63%
	Common tiger butterfly	18.32%	23.25%	22.72%
	Grey pansy	1.57%	6.97%	8.18%
	Danaid eggfly	0.52%	2.32%	3.63%

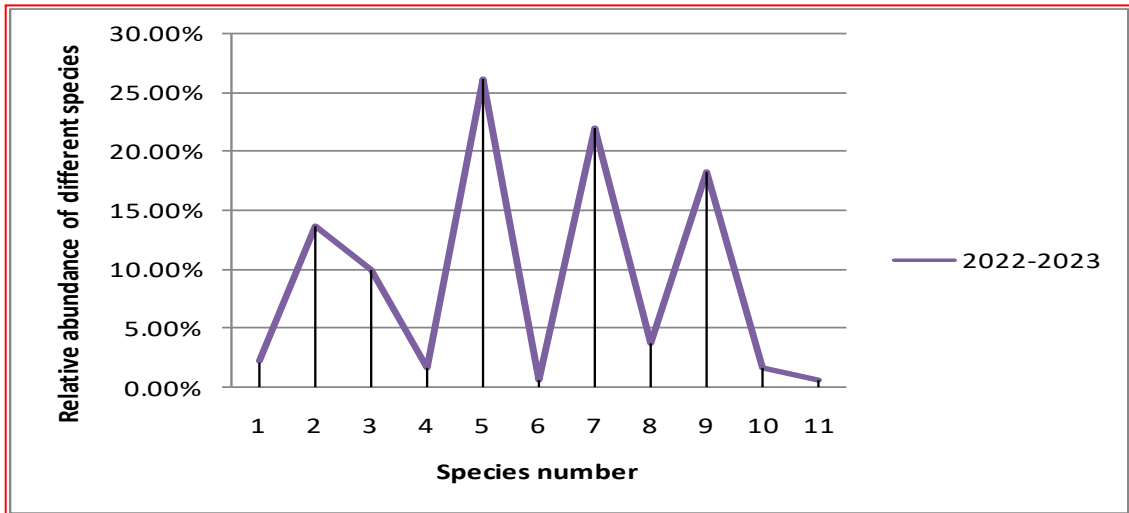


Fig 8a- Variation in relative abundance of different species at site 2 during the year 2022-2023.

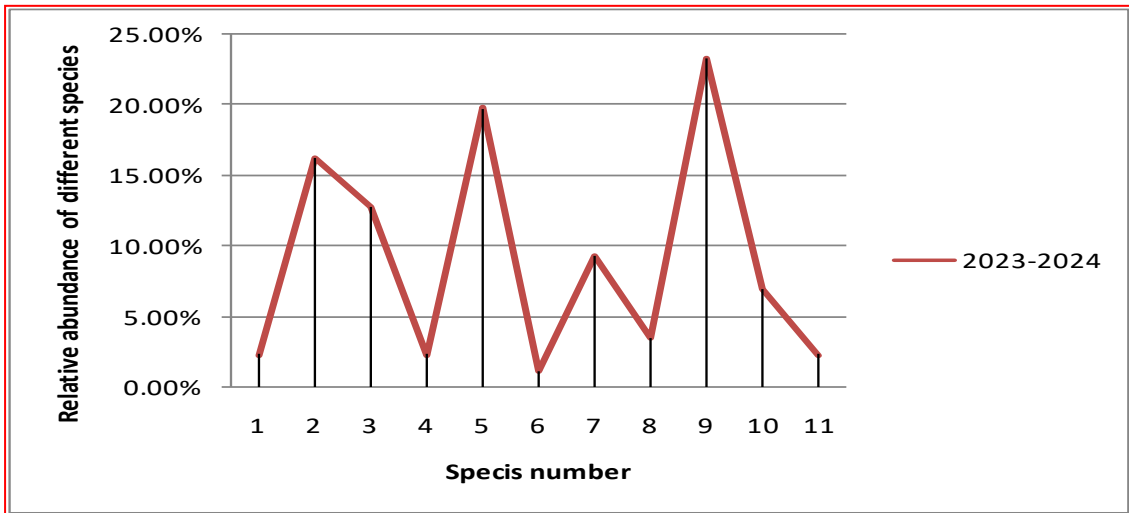


Fig 8b- Variation in relative abundance of different species at site 2 during the year 2023-2024.

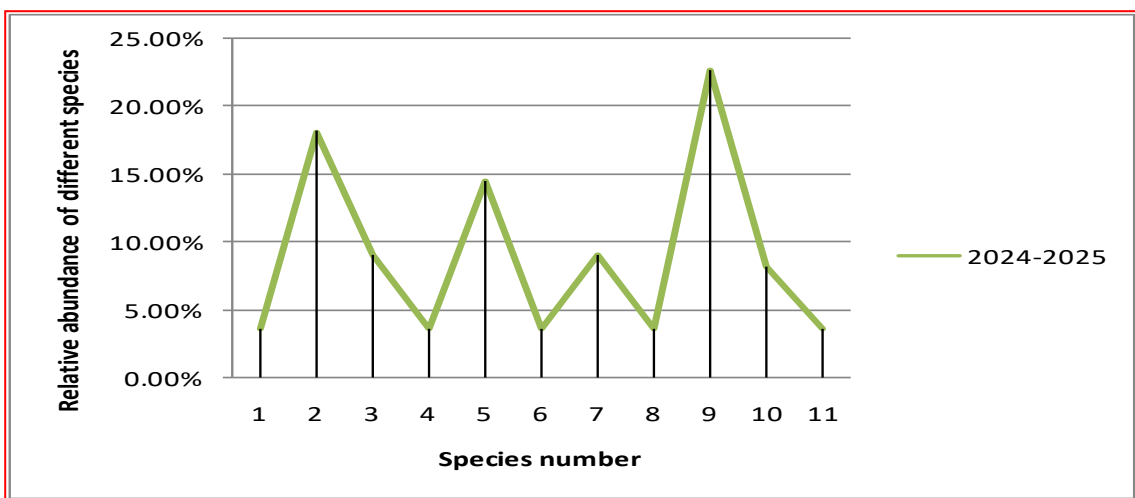


Fig 8c- Variation in relative abundance of different species at site 2 during the year 2024-2025.

Across the three years of observation, species richness at site 2 remained unchanged, and it consistently exhibited lower richness than site 1. The community at site 2 was dominated by a few species, reflecting moderate evenness. Overall, site 2 supported comparatively lower biodiversity than site 1.

In the year 2022-2023 at site 3 total 30 individuals were recorded. The most abundant species at site 3 was common tiger butterfly (26.66%) and the least abundant species were blue pansy and grey pansy (3.33% each). At site 3 in the year 2022-2023, six abundant species constituted 93.31% of the total individuals whereas the remaining 2 species collectively shared 6.69% of the community composition.

Altogether 37 individuals were recorded at site 3 in the year 2023-2024. Common tiger butterfly (24.32%) was the most abundant species at site 3 in this year and the least abundant species were pale grass blue and Grey pansy (5.40% each). Observations from site 3 indicated that 6 species represented 89.16% of the butterfly community, while 2 species contributed 10.84% to the community structure.

Overall 61 individuals were recorded at site 3 in the year 2024-2025. The most abundant species was common tiger butterfly (19.67%) and the least abundant species were grass jewel and blue pansy (6.55% each). At site 3 in the year 2024-2025, six abundant species constituted 86.86% of the butterfly community whereas the remaining 2 species collectively share 13.14% of the community composition.

Throughout the three years of study at site 3, common tiger butterfly was recorded as the most abundant species. This indicates that, over time, the species composition remains largely unchanged, reflecting ecosystem stability. However, sustained dominance by a single species can lower evenness, as it disproportionately influences the overall community structure.

Table 7: Relative abundance of butterflies species over three years at site 3

Families	Species	2022-2023	2023-2024	2024-2025
Pieridae (2)	Spotless grass yellow	16.66%	21.62%	16.39%
	Common grass yellow	13.33%	8.10%	8.19%
Lycaenidae (2)	Grass jewel	10%	13.51%	6.55%
	Pale grass blue	10%	5.40%	14.75%
Nymphalidae (4)	Blue Pansy	3.33%	8.10%	6.55%
	Plain tiger butterfly	16.66%	13.51%	14.75%
	Common tiger butterfly	26.66%	24.32%	19.67%
	Grey pansy	3.33%	5.40%	13.11%

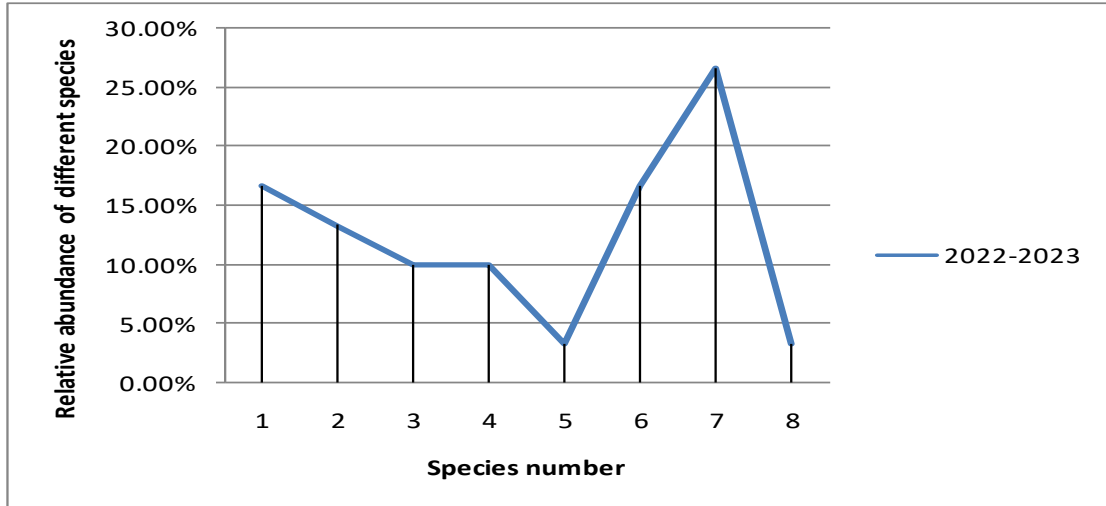


Fig 9a- Variation in relative abundance of different species at site 3 during the year 2022-2023.

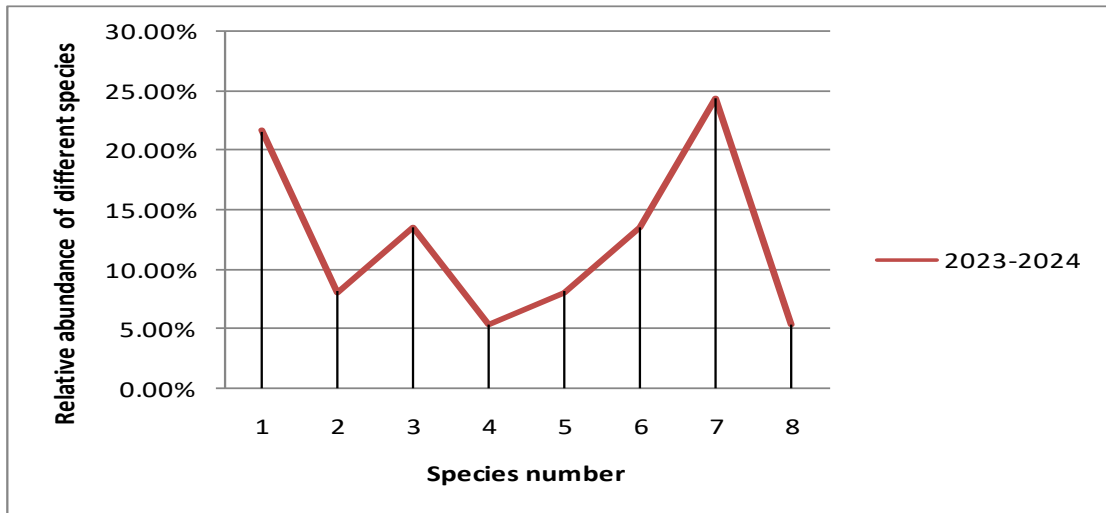


Fig 9b- Variation in relative abundance of different species at site 3 during the year 2023-2024.

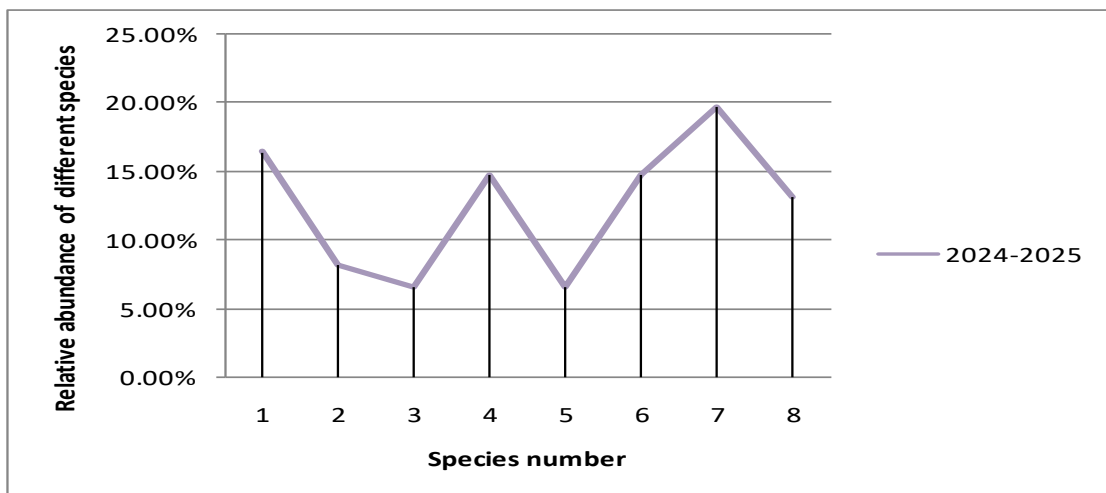


Fig 9c- Variation in relative abundance of different species at site 3 during the year 2024-2025.

In the three consecutive years site 3 shows lower species richness as compared to all the other three sites. The curve of graph is comparatively flat slope indicating the high evenness in the community. Such results indicate a community with balanced representation of species but minimal diversity because of the lesser number of species present at the study site.

In the year 2022-2023 at site 4 total 1186 individuals were recorded. Plain tiger butterfly (5.90%) was the most abundant species and the least abundant species was rice swift (0.16%) at site 4 in the current year. Observations from site 4 indicated that 7 species constituted 33.69% of the total butterflies while 31 species contributed 66.31% to the community structure.

Altogether 1204 individuals were recorded at site 4 in the year 2023-2024. The most abundant species was common grass yellow (5.48%) and the least abundant species were rice swift and common rose swallowtail (0.49%). In the present year out of the total butterflies 34.61% belong to seven species while the remaining 31 species accounted for 65.39%.

Overall 1326 individuals were recorded at site 4 in the year 2024-2025. The highest abundance was showed by plain tiger butterfly (5.27%) while the least abundance was showed by common rose swallowtail and rice swift (0.52% each). In the current year seven species contributed 33.97% of the total butterfly population whereas the remaining 31 species together accounted for 66.03%.

In the first year at site 4, plain tiger butterfly exhibited highest abundance whereas this dominance was replaced by common grass yellow in the second year. While in the third year of study plain tiger butterfly regained dominance. Such change in the composition of community indicates that the ecosystem is not stable it is in continuous ecological pressure.

Table 8: Relative abundance of butterfly species over three years at site 4

Family	Species	2022-2023	2023-2024	2024-2025
Papilionidae	Common jay	1.51%	0.99%	1.05%
	Common rose swallowtail	0.92%	0.49%	0.52%
	Common mormon swallowtail	1.34%	0.91%	0.75%
	Lime swallowtail	0.92%	0.83%	1.43%
Pieridae	Mottled emigrant	1.60%	1.49%	1.50%
	Spotless grass yellow	4.80%	3.73%	3.69%
	Common grass yellow	4.80%	5.48%	5.12%
	Striped albatross	3.20%	4.15%	3.69%
	Common gull	4.30%	3.32%	2.86%
	Pioneer white	4.80%	5.06%	4.90%
	Common jezebel	2.44%	2.07%	2.26%
	White orange tip	2.19%	3.65%	3.46%
Lycaenidae	Common emigrant	4.04%	5.06%	4.90%
	Grass jewel	2.36%	3.32%	2.63%
	Dark grass blue	1.43%	3.15%	3.01%
	Striped pierrot	2.27%	2.90%	3.16%
	Pale grass blue	1.34%	4.65%	4.44%
	Forget-me-not	3.54%	1.49%	1.50%
	Zebra blue	1.93%	0.99%	1.05%
Nymphalidae	Lime blue	2.69%	1.24%	1.50%
	Blue pansy	1.34%	0.91%	1.13%
	Plain tiger butterfly	5.90%	5.31%	5.27%
	Lemon pansy	2.52%	3.82%	3.01%
	Tawny coster	3.37%	3.48%	3.69%
	Common tiger butterfly	5.05%	3.32%	2.63%
	Grey pansy	3.96%	4.90%	4.82%
	Danaid eggfly	3.62%	3.98%	4.52%
	Chocolate pansy	2.36%	3.07%	3.54%
	Common castor butterfly	2.27%	1.32%	3.39%
	Angled castor	1.77%	0.99%	1.13%
	Common evening brown	2.10%	2.15%	1.96%
	Peacock pansy	2.27%	2.24%	1.88%
	Blue tiger	2.44%	0.91%	1.13%
	Common leopard	1.93%	1.16%	1.20%
Common crow	2.86%	1.49%	1.50%	
Hesperiidae	Great eggfly	2.78%	3.98%	3.69%
	Rice swift	0.16%	0.49%	0.52%
	Indian palm bob	0.67%	1.32%	1.35%

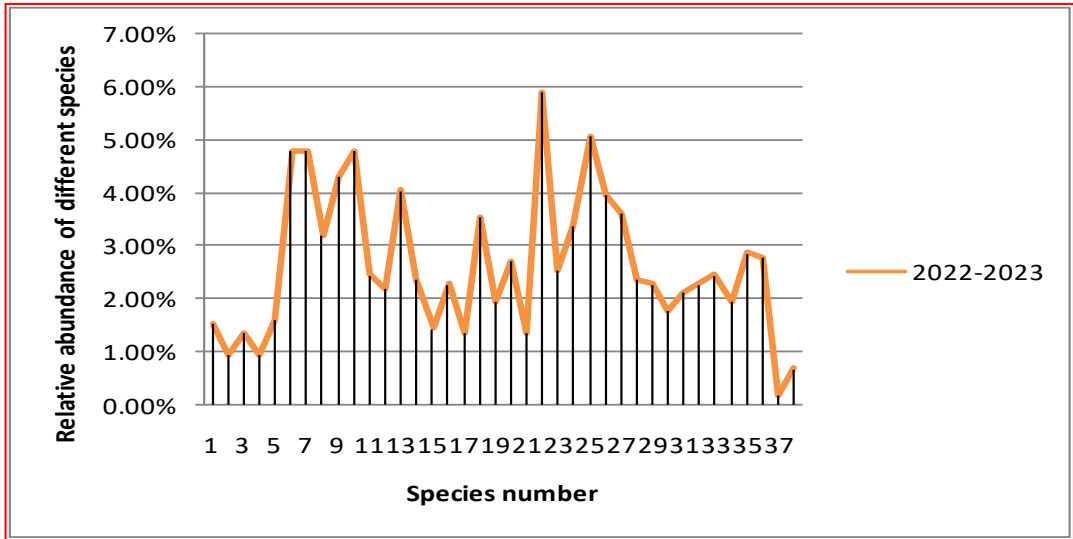


Fig 10a- Variation in relative abundance of different species at site 4 during the year 2022-2023.

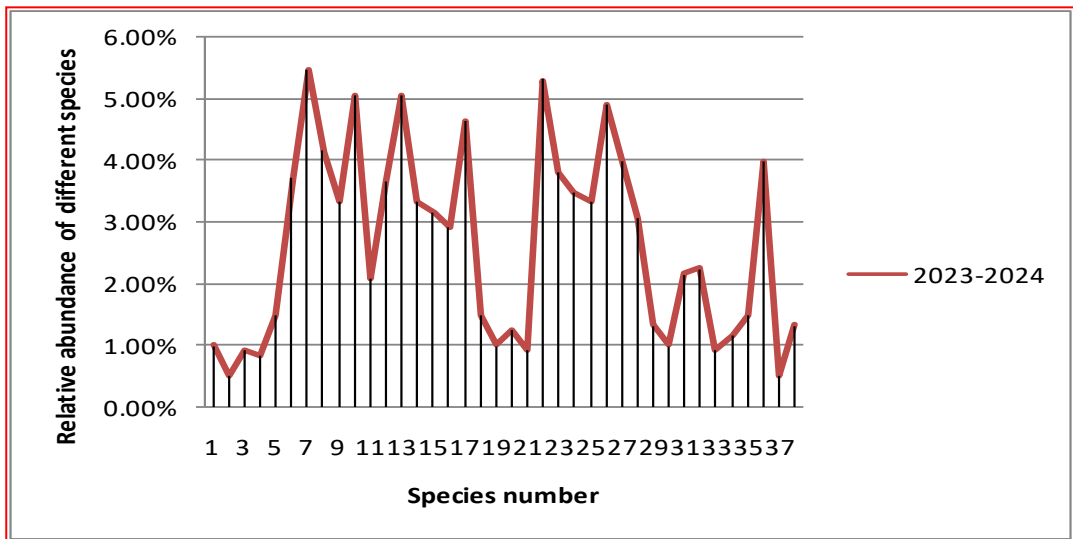


Fig 10b- Variation in relative abundance of different species at site 4 during the year 2023-2024.

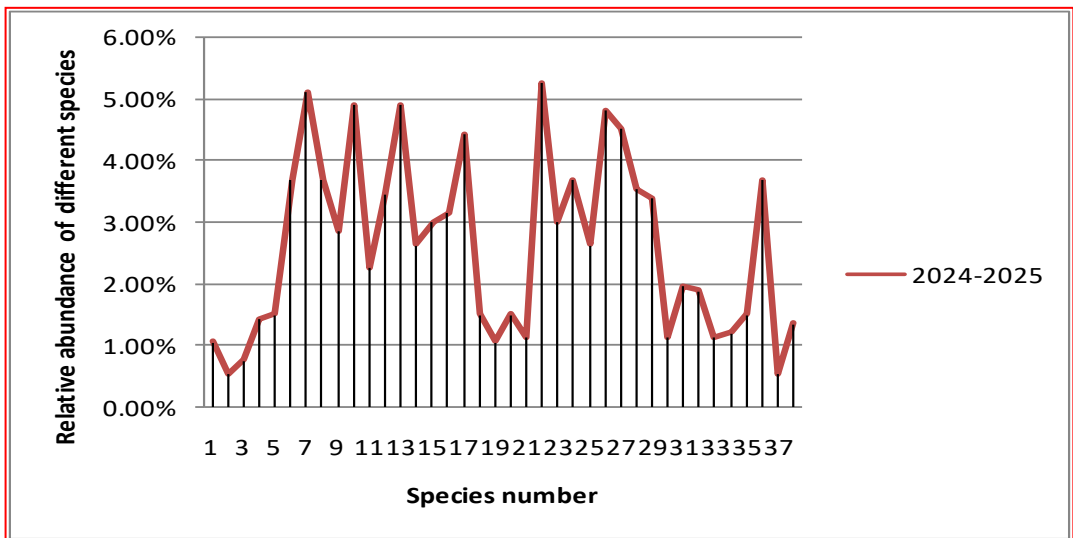


Fig 10c- Variation in relative abundance of different species at site 4 during the year 2024-2025.

Site 4 demonstrates highest species richness and high evenness, it suggests that a large number of species are present and the individuals are distributed almost equally among them. No single species was dominating in the community. Such pattern reflects a ecologically stable and highly diverse community. In this community species coexists in a well balanced manner.

In the year 2022-2023 the most abundant butterfly in the overall study area was plain tiger butterfly. Whereas in the year 2023-2024 & 2024-2025 common grass yellow was the most abundant butterfly in the overall study area.

(C) Beta Diversity

Beta diversity describes the differences in species composition among habitats, sites, or communities within a given region. It provides an evaluation of the variation among communities by indicating the extent of similarity or dissimilarity in the species they comprise.

By using the Jaccard index beta diversity of the study site was evaluated. Similarity in species composition between the sites is analyzed based on the presence or absence of species. Pair wise Jaccard similarity index value across the four different sites varied from 0.15 to 0.30.

In the first year mean similarity was 0.23 and the computed average dissimilarity across the all site pairs was 0.77. This result indicates that 77% of the species composition was dissimilar between the sites. In the year 2022-2023 site 2 and site 3 showed the highest similarity ($J= 0.30$), reflecting that site 2 and site 3 shared a comparatively large proportion of species. While site 3 and site 4 shared least species in common. Site 1 and site 2 also shared a high proportion of the species.

In the following two years mean similarity was 0.22 and the average dissimilarity across the all site pairs was 0.78. This suggests that 78% of the species composition was dissimilar between the sites. In these two years Jaccard

similarity index remained exactly same for each pair of sites indicating no change in species composition.

The observed high dissimilarity values among sites indicates substantial variation in community composition suggesting significant species turnover and heterogeneous ecological structure.

Table 9: Comparison of Jaccard's Index (2022-2023, 2023-2024 & 2024-2025)

Sites	2022-2023		2023-2024		2024-2025	
	Jaccard similarity	Jaccard dissimilarity	Jaccard similarity	Jaccard dissimilarity	Jaccard similarity	Jaccard dissimilarity
S1-S2	0.27	0.73	0.23	0.77	0.23	0.77
S1-S3	0.23	0.77	0.19	0.81	0.19	0.81
S1-S4	0.25	0.75	0.28	0.72	0.28	0.72
S2-S3	0.30	0.7	0.30	0.7	0.30	0.7
S2-S4	0.18	0.82	0.18	0.82	0.18	0.82
S3-S4	0.15	0.85	0.15	0.85	0.15	0.85

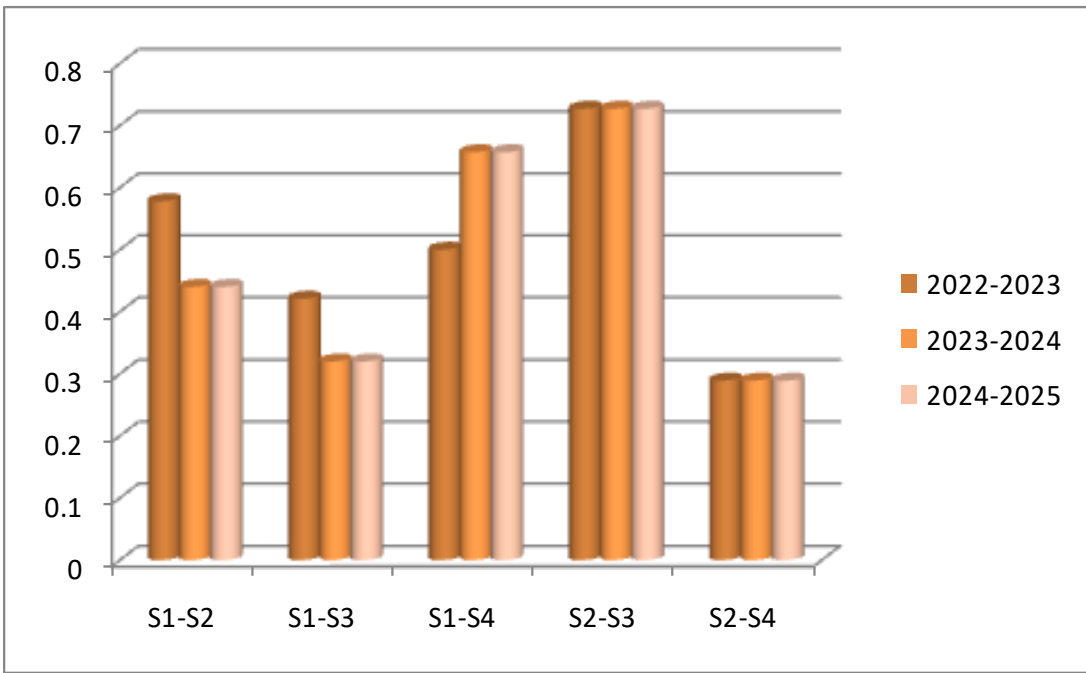


Fig 11a- Graph showing Jaccard's Index (Similarity index).

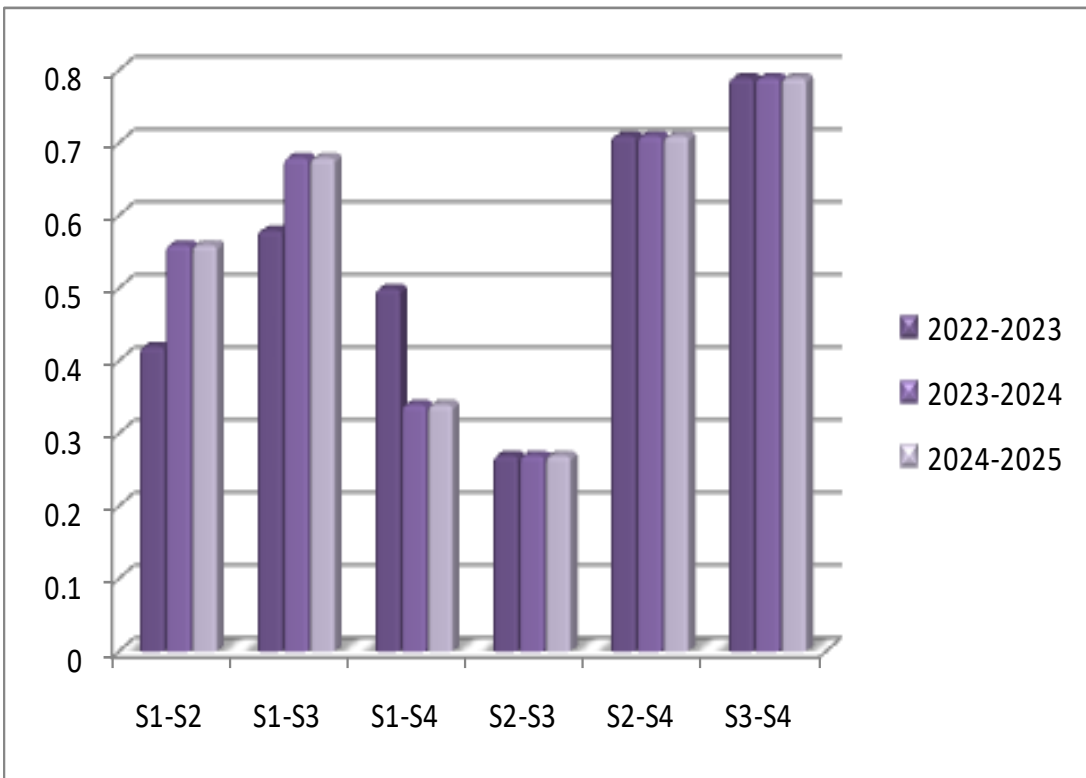


Fig 11b- Graph showing Jaccard's Index (Dissimilarity index).

(D) Gamma diversity

Gamma diversity measures the cumulative species richness of all the surveyed sites reflecting the overall biodiversity of the region investigated.

In the present study gamma diversity of all the four sites was found to be 38 species, site 1 contributed 25 species, site 2 contributed 11 species, site 3 contributed 8 species and site 4 contributed 38 species.

In the present study gamma diversity was estimated by combining the species recorded from all the sites. The documented gamma diversity highlights the heterogeneity of the investigated region. The gamma diversity of the study sites reflects that each site adds a distinct contribution to the biodiversity of the region.

Some species (spotless grass yellow, common grass yellow, grass jewel, pale grass blue, blue pansy, plain tiger butterfly, common tiger butterfly and grey pansy) were consistently present across all the study sites, indicating widespread distribution. Their continuous presence is likely supported by the availability of common host and nectar plants in the area. For instance, plain tiger and common tiger utilize *Calotropis spp.* as host plants, while grass jewel and pale grass blue depend on Leguminosae herbs, and blue pansy and grey pansy frequent *Lantana spp.* and grasses for nectar. Similarly, spotless grass yellow and common grass yellow are associated with Fabaceae and Gramineae plants. The consistent occurrence of these species highlights the crucial role of these plants in sustaining butterfly populations across different habitats.

Whereas some other species (Indian palm bob, common crow, common leopard, blue tiger, peacock pansy, common evening brown, angled castor, lime blue, common emigrant, white orange tip, common jezebel, pioneer white and common gull) were confined to a single site (site 4), reflecting site-specific occurrence. Their restricted occurrence is likely linked to the presence of specific host and nectar plants such as palms, *Calotropis spp.*, *Ricinus communis*, Fabaceae, Capparaceae, and Brassicaceae. This indicates that plant availability plays a crucial role in determining the localized distribution of these butterfly species.

Table 10: Comparison of Gamma Diversity at four different sites of study area

Sites	Number of families of butterflies			Number of species of butterflies		
	2022-23	2023-24	2024-25	2022-23	2023-24	2024-25
1	5	5	5	19	25	25
2	3	3	3	11	11	11
3	3	3	3	8	8	8
4	5	5	5	38	38	38
Gamma diversity	5	5	5	38	38	38

Table 11: Presence and absence of butterfly species across study sites

Family	Species	Site 1	Site 2	Site 3	Site 4
Papilionidae	Common jay	+			+
	Common rose swallowtail	+			+
	Common mormon swallowtail	+			+
	Lime swallowtail	+			+
Pieridae	Mottled emigrant	+	+		+
	Spotless grass yellow	+	+	+	+
	Common grass yellow	+	+	+	+
	Striped albatross	+			+
	Common gull				+
	Pioneer white				+
	Common jezebel				+
	White orange tip				+
	Common emigrant				+
Lycaenidae	Grass jewel	+	+	+	+
	Dark grass blue	+			+
	Striped pierrot	+			+
	Pale grass blue	+	+	+	+
	Forget-me-not	+			+
	Zebra blue	+			+
	Lime blue				+
Nymphalidae	Blue pansy	+	+	+	+
	Plain tiger butterfly	+	+	+	+

	Lemon pansy	+	+		+
	Tawny coster	+			+
	Common tiger butterfly	+	+	+	+
	Grey pansy	+	+	+	+
	Danaid eggfly	+	+		+
	Chocolate pansy	+			+
	Common castor butterfly	+			+
	Angled castor				+
	Common evening brown				+
	Peacock pansy				+
	Blue tiger				+
	Common leopard				+
	Common crow				+
	Great eggfly	+			+
Hesperiidae	Rice swift	+			+
	Indian palm bob				+

Table 12: List of Collected Butterfly Species with their Host Plants and nectar plants

Family	Species	Host Plants	Nectar Plants
Papilionidae	Common Jay	<i>Citrus spp.</i> , <i>Murraya paniculata</i> , <i>Hibiscus rosa-sinensis</i> , <i>Azadirachta indica</i> , <i>Calotropis procera</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Murraya paniculata</i>
	Common Rose Swallowtail	<i>Citrus spp.</i> , <i>Murraya paniculata</i> , <i>Hibiscus rosa-sinensis</i> , <i>Azadirachta indica</i> , <i>Calotropis procera</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Murraya paniculata</i>
	Common Mormon Swallowtail	<i>Citrus spp.</i> , <i>Murraya paniculata</i> , <i>Hibiscus rosa-sinensis</i> , <i>Azadirachta indica</i> , <i>Calotropis procera</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Murraya paniculata</i>
	Lime Swallowtail	<i>Citrus spp.</i> , <i>Murraya paniculata</i> , <i>Hibiscus rosa-sinensis</i> , <i>Azadirachta indica</i> , <i>Calotropis procera</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Murraya paniculata</i>
Pieridae	Mottled Emigrant	<i>Tamarindus indica</i> , <i>Cajanus cajan</i> , <i>Azadirachta indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Murraya paniculata</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Rosa rubiginosa</i> , <i>Tagetes erecta</i>
	Spotless Grass Yellow	<i>Tamarindus indica</i> , <i>Cajanus cajan</i> , <i>Azadirachta indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Murraya paniculata</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Rosa rubiginosa</i> , <i>Tagetes erecta</i>
	Common Grass Yellow	<i>Tamarindus indica</i> , <i>Cajanus cajan</i> , <i>Azadirachta indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Murraya paniculata</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Rosa rubiginosa</i> , <i>Tagetes erecta</i>
	Striped Albatross	<i>Tamarindus indica</i> , <i>Cajanus cajan</i> , <i>Azadirachta indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Murraya paniculata</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Rosa rubiginosa</i> , <i>Tagetes erecta</i>

	Common Gull	<i>Tamarindus indica</i> , <i>Cajanus cajan</i> , <i>Azadirachta indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Murraya paniculata</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Rosa rubiginosa</i> , <i>Tagetes erecta</i>
	Pioneer White	<i>Tamarindus indica</i> , <i>Cajanus cajan</i> , <i>Azadirachta indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Murraya paniculata</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Rosa rubiginosa</i> , <i>Tagetes erecta</i>
	Common Jezebel	<i>Tamarindus indica</i> , <i>Cajanus cajan</i> , <i>Azadirachta indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Murraya paniculata</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Rosa rubiginosa</i> , <i>Tagetes erecta</i>
	White Orange Tip	<i>Tamarindus indica</i> , <i>Cajanus cajan</i> , <i>Azadirachta indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Murraya paniculata</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Rosa rubiginosa</i> , <i>Tagetes erecta</i>
	Common Emigrant	<i>Tamarindus indica</i> , <i>Cajanus cajan</i> , <i>Azadirachta indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Murraya paniculata</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i> , <i>Rosa rubiginosa</i> , <i>Tagetes erecta</i>
Lycaenidae	Grass Jewel	<i>Cajanus cajan</i> , <i>Tamarindus indica</i> , <i>Azadirachta indica</i> , <i>Murraya paniculata</i> , <i>Hibiscus rosa-sinensis</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i>
	Dark Grass Blue	<i>Cajanus cajan</i> , <i>Tamarindus indica</i> , <i>Azadirachta indica</i> , <i>Murraya paniculata</i> , <i>Hibiscus rosa-sinensis</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i>
	Striped Pierrot	<i>Cajanus cajan</i> , <i>Tamarindus indica</i> , <i>Azadirachta indica</i> , <i>Murraya paniculata</i> , <i>Hibiscus rosa-sinensis</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i>
	Pale Grass Blue	<i>Cajanus cajan</i> , <i>Tamarindus indica</i> , <i>Azadirachta indica</i> , <i>Murraya paniculata</i> , <i>Hibiscus rosa-sinensis</i>	<i>Lantana camara</i> , <i>Phlox spp.</i> , <i>Nelumbo nucifera</i> , <i>Lagerstroemia indica</i> , <i>Hibiscus rosa-sinensis</i>

	Forget-me-not	<i>Cajanus cajan, Tamarindus indica, Azadirachta indica, Murraya paniculata, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica, Hibiscus rosa-sinensis</i>
	Zebra Blue	<i>Cajanus cajan, Tamarindus indica, Azadirachta indica, Murraya paniculata, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica, Hibiscus rosa-sinensis</i>
	Lime Blue	<i>Cajanus cajan, Tamarindus indica, Azadirachta indica, Murraya paniculata, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica, Hibiscus rosa-sinensis</i>
Nymphalidae	Blue Pansy	<i>Cajanus cajan, Tamarindus indica, Azadirachta indica, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica, Hibiscus rosa-sinensis</i>
	Plain Tiger	<i>Citrus spp., Murraya paniculata, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica, Hibiscus rosa-sinensis</i>
	Lemon Pansy	<i>Cajanus cajan, Tamarindus indica, Azadirachta indica, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica, Hibiscus rosa-sinensis</i>
	Tawny Coster	<i>Cajanus cajan, Tamarindus indica, Azadirachta indica, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica, Hibiscus rosa-sinensis</i>
	Common Tiger Butterfly	<i>Citrus spp., Murraya paniculata, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica, Hibiscus rosa-sinensis</i>
	Grey Pansy	<i>Cajanus cajan, Tamarindus indica, Azadirachta indica, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica, Hibiscus rosa-sinensis</i>
	Danaid Eggfly	<i>Citrus spp., Murraya paniculata, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica, Hibiscus rosa-sinensis</i>
	Chocolate	<i>Cajanus cajan, Tamarindus</i>	<i>Lantana camara, Phlox spp., Nelumbo</i>

	Pansy	<i>indica, Azadirachta indica, Hibiscus rosa-sinensis</i>	<i>nucifera, Lagerstroemia indica, Hibiscus rosa-sinensis</i>
	Common Castor Butterfly	<i>Ricinus communis, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica, Hibiscus rosa-sinensis</i>
	Angled Castor	<i>Ricinus communis, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica, Hibiscus rosa-sinensis</i>
	Common Evening Brown	<i>Cajanus cajan, Tamarindus indica, Azadirachta indica</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica</i>
	Peacock Pansy	<i>Cajanus cajan, Tamarindus indica, Azadirachta indica</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica</i>
	Blue Tiger	<i>Citrus spp., Murraya paniculata, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica</i>
	Common Leopard	<i>Cajanus cajan, Tamarindus indica, Azadirachta indica</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica</i>
	Common Crow	<i>Citrus spp., Murraya paniculata, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica</i>
	Great Eggfly	<i>Citrus spp., Murraya paniculata, Hibiscus rosa-sinensis</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica</i>
Hesperiidae	Rice Swift	<i>Oryza sativa</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica</i>
	Indian Palm Bob	<i>Areca catechu</i>	<i>Lantana camara, Phlox spp., Nelumbo nucifera, Lagerstroemia indica</i>

(E) Seasonality pattern of butterflies in the study area

Seasonal occurrence and abundance of butterflies provides an important insight into the resources availability and ecological factors (temperature and humidity) which affect these Lepidopteran fauna. In Lepidoptera seasonal variation play a significant role in shaping the community structure as butterflies are highly sensitive to the fluctuating climatic conditions and resources availability.

Over the seasons remarkable differences in butterfly abundance and distribution was observed which is due to variation in climatic factors (such as temperature, humidity and rainfall) and ecological resources.

Data on seasonal records of butterfly species were recorded to evaluate their temporal distribution. Species richness and abundance both vary across different months. The abundance and diversity was highest during the post-monsoon season in the study area and was found lowest during winter season. In the post-monsoon season the host plants and nectar plants are available in abundance synchronizing with favourable temperature and increased humidity. These conditions create a suitable environment for foraging, dispersal and breeding in turn supporting the highest butterfly dynamics.

On the other hand during winter season low temperature and declined vegetation cover created unfavourable conditions for butterflies leading to low species richness and abundance. This decrease indicates that these adverse conditions act as a limiting factor for the sustenance of many species. Our findings align with the results of Rani and Ahmed (2021), they stated that maximum number of species were observed during the post monsoon season followed by monsoon, summer and winter respectively. Diversity peak of butterflies were recorded in September during the study period. Similar results were presented by Keshre and Upadhya (2023), they reported that peak in September is due to the presence of host and nectar plants.

Such seasonal patterns indicate that distribution and activity of butterflies is significantly affected by the seasonal ecological factors like availability of

resources, temperature and humidity. These outcomes of the present study emphasize the importance of seasonality in governing the community structure of butterflies. As a whole the results indicate that seasonal variation serves a key role in governing the abundance, distribution and community composition of butterfly fauna.

The seasonal variation (family-wise) graphs reveals noticeable fluctuations in butterfly abundance across different seasons. Families highest peak of abundance was observed during the post-monsoon season followed by monsoon, summer and winter. The overall trend suggests that butterfly diversity and abundance are strongly influenced by seasonal factors such as rainfall, temperature, humidity and the availability of flowering as well as host plants. These fluctuations highlight the importance of seasonal changes in shaping the population dynamics of butterfly families in the study area.

In the first year of study during winter (December–March), the average temperature ranged from 17.2 to 26.7 °C, rainfall varied between 3.4 and 10.3 mm, and relative humidity ranged from 22 to 44 %. In summer (April–June), temperatures ranged from 32.8 to 36.1 °C, rainfall from 6.9 to 85.9 mm, and humidity from 16 to 41 %. The monsoon season (July–August) recorded temperatures between 28.9 and 30.6 °C, heavy rainfall from 261.1 to 268.0 mm, and humidity between 66 and 74 %. During the post-monsoon period (September–November), temperatures ranged from 23.3 to 29.4 °C, rainfall from 3.4 to 106.5 mm, and relative humidity from 37 to 63 %.

During the year 2023-2024, analysis of seasonal climatic parameters showed that during winter (December–March), average temperatures ranged from 17.2 to 26.7 °C, rainfall varied between 3.8 and 11.5 mm, and relative humidity ranged from 22 to 44 %. In summer (April–June), temperatures ranged from 32.8 to 36.1 °C, rainfall from 7.7 to 95.6 mm, and humidity from 16 to 41 %. The monsoon season (July–August) experienced temperatures between 28.9 and 30.6 °C, heavy rainfall from 290.9 to 298.8 mm, and relative humidity between 66 and 74 %. During the post-monsoon period (September–November), temperatures

ranged from 23.3 to 29.4 °C, rainfall from 3.8 to 118.8 mm, and humidity from 37 to 63 %.

In the year 2024-2025, seasonal climatic analysis showed that during winter (December–March), temperatures ranged from 17.2 to 26.7 °C, rainfall from 3.3 to 9.8 mm, and relative humidity from 22 to 44 %. In summer (April–June), temperatures ranged from 32.8 to 36.1 °C, rainfall from 6.6 to 82.2 mm, and humidity from 16 to 41 %. The monsoon season (July–August) recorded temperatures between 28.9 and 30.6 °C, heavy rainfall from 250.1 to 256.8 mm, and humidity from 66 to 74 %. During the post-monsoon period (September–November), temperatures ranged from 23.3 to 29.4 °C, rainfall from 3.3 to 102.1 mm, and relative humidity from 37 to 63 %.

In January 2025, the average temperature was 17.2 °C, with rainfall measuring 10.6 mm and relative humidity at 44%. In February 2025, temperatures rose slightly to 20.6 °C, rainfall increased to 15.8 mm, and humidity decreased to 33%. These observations, compiled from WeatherSpark (2025) and adjusted using annual rainfall totals reported by the India Meteorological Department (2022–2025), provided the climatic framework for interpreting the study results.

In the study consistent relationship was observed between seasonal climatic conditions and butterfly diversity and abundance during the three years of study. Throughout the study period, post-monsoon season (September–November) provided the most favorable conditions, with moderate temperatures, sufficient rainfall, and relatively high humidity, resulting in the highest butterfly richness and abundance across the three years of study. The monsoon season (July–August), characterized by heavy rainfall and high humidity, also supported large butterfly populations, though excessive rainfall likely limited their flight activity, making abundance slightly lower than in post-monsoon. In contrast, summer (April–June), with extreme temperatures, low humidity, and limited rainfall, showed reduced butterfly numbers. The winter months (December–March), being the coldest and driest period with minimal floral resources, consistently recorded the lowest diversity and abundance. This trend highlights that butterfly populations respond positively to moderate climatic conditions with adequate

moisture and vegetation growth, but both extreme dryness and excessive rainfall reduce their activity and diversity.

Table 13: Monthly Climate Data of Kota, Rajasthan in the year 2022

(Source: WeatherSpark 2025; IMD 2022–2025)

Month	Average temp (°C)	Rain (mm)	Average RH (%)
Jan.	17.2	6.9	44
Feb.	20.6	10.3	33
Mar.	26.7	6.9	22
Apr.	32.8	6.9	16
May	36.1	13.8	24
Jun.	34.4	85.9	41
Jul.	30.6	261.1	66
Aug.	28.9	268.0	74
Sep.	29.4	106.5	63
Oct.	28.3	20.6	45
Nov.	23.3	3.4	37
Dec.	18.9	3.4	44

Table 14: Seasonal ranges of temperature, rainfall, and relative humidity in the year 2022

Season	Temperature (°C)	Rainfall (mm)	Relative Humidity (%)
Winter (Dec.–Mar.)	17.2 – 26.7	3.4 – 10.3	22 – 44
Summer (Apr.–Jun.)	32.8 – 36.1	6.9 – 85.9	16 – 41
Monsoon (Jul.–Aug.)	28.9 – 30.6	261.1 – 268.0	66 – 74
Post-Monsoon (Sep.–Nov.)	23.3 – 29.4	3.4 – 106.5	37 – 63

Table 15: Monthly Climate Data of Kota, Rajasthan in the year 2023

(Source: WeatherSpark 2025; IMD 2022–2025)

Month	Average temp (°C)	Rain (mm)	Average RH (%)
Jan.	17.2	7.7	44
Feb.	20.6	11.5	33
Mar.	26.7	7.7	22
Apr.	32.8	7.7	16
May	36.1	15.4	24
Jun.	34.4	95.6	41
Jul.	30.6	290.9	66
Aug.	28.9	298.8	74
Sep.	29.4	118.8	63
Oct.	28.3	23.0	45
Nov.	23.3	3.8	37
Dec.	18.9	3.8	44

Table 16: Seasonal ranges of temperature, rainfall, and relative humidity
in the year 2023

Season	Temperature (°C)	Rainfall (mm)	Relative Humidity (%)
Winter (Dec.– Mar.)	17.2 – 26.7	3.8 – 11.5	22 – 44
Summer (Apr.– Jun.)	32.8 – 36.1	7.7 – 95.6	16 – 41
Monsoon (Jul.– Aug.)	28.9 – 30.6	290.9 – 298.8	66 – 74
Post-Monsoon (Sep.– Nov.)	23.3 – 29.4	3.8 – 118.8	37 – 63

Table 17: Monthly Climate Data of Kota, Rajasthan in the year 2024
(Source: WeatherSpark 2025; IMD 2022–2025)

Month	Average temp (°C)	Rain (mm)	Average RH (%)
Jan.	17.2	6.6	44
Feb.	20.6	9.8	33
Mar.	26.7	6.6	22
Apr.	32.8	6.6	16
May	36.1	13.2	24
Jun.	34.4	82.2	41
Jul.	30.6	250.1	66
Aug.	28.9	256.8	74
Sep.	29.4	102.1	63
Oct.	28.3	19.8	45
Nov.	23.3	3.3	37
Dec.	18.9	3.3	44

Table 18: Seasonal ranges of temperature, rainfall, and relative humidity in the year 2024

Season	Temperature (°C)	Rainfall (mm)	Relative Humidity (%)
Winter (Dec.– Mar.)	17.2 – 26.7	3.3 – 9.8	22 – 44
Summer (Apr.– Jun.)	32.8 – 36.1	6.6 – 82.2	16 – 41
Monsoon (Jul.– Aug.)	28.9 – 30.6	250.1 – 256.8	66 – 74
Post-Monsoon (Sep.– Nov.)	23.3 – 29.4	3.3 – 102.1	37 – 63

Table 19: Monthly Climate Data of Kota, Rajasthan in the year 2025

(Source: WeatherSpark 2025; IMD 2022–2025)

Month	Average temp (°C)	Rain (mm)	Average RH (%)
Jan.	17.2	10.6	44
Feb.	20.6	15.8	33

Table 20: Seasonality of different species of butterflies at site 1 across three years of study

Family	Species	2022-2023				2023-2024				2024-2025			
		Monsoon (July-Aug)	Post-Monsoon (Sept-Nov)	Summer (April-June)	Winter (Dec-March)	Monsoon (July-Aug)	Post-Monsoon (Sept-Nov)	Summer (April-June)	Winter (Dec-March)	Monsoon (July-Aug)	Post-Monsoon (Sept-Nov)	Summer (April-June)	Winter (Dec-March)
Papilionidae	Common jay	1	2	0	0	2	3	1	0	1	2	0	0
	Common rose swallowtail	0	1	0	0	1	2	0	0	1	3	0	0
	Common mormon swallowtail	1	2	0	0	1	2	0	0	1	1	0	0
	Lime swallowtail	0	0	0	0	0	1	0	0	1	2	0	0
Pieridae	Mottled emigrant	2	5	1	1	5	7	3	1	4	6	2	2
	Spotless grass yellow	11	14	9	9	11	13	8	2	12	13	9	2
	Common grass yellow	4	14	3	2	10	15	9	7	12	20	9	7
	Striped albatross	0	1	0	0	7	10	6	3	7	11	6	3
Lycaenidae	Grass jewel	3	4	2	2	6	9	4	1	5	9	4	1

	Dark grass blue	0	2	0	0	2	4	1	0	2	5	1	0
	Striped pierrot	0	1	0	0	2	5	1	0	1	4	1	0
	Pale grass blue	0	3	0	0	3	8	2	1	2	7	2	1
	Forget-me-not	0	0	0	0	3	5	1	0	3	6	1	0
	Zebra blue	0	0	0	0	2	3	0	0	1	3	0	0
Nymphalidae	Blue pansy	1	1	1	0	4	5	2	1	4	6	2	1
	Plain tiger butterfly	12	22	6	3	10	14	9	6	9	13	8	6
	Lemon pansy	1	5	1	0	3	6	4	2	6	9	4	2
	Tawny coster	2	3	1	1	4	8	2	1	6	11	2	1
	Common tiger butterfly	10	16	6	3	12	14	7	5	12	11	7	5
	Grey pansy	1	1	1	0	3	5	2	0	7	10	3	0

	Danaid eggfly	2	3	1	0	3	6	1	0	4	9	2	0
	Great eggfly	0	0	0	0	4	5	0	0	4	6	1	0
	Common castor	0	0	0	0	4	6	2	1	5	7	2	1
	Chocolate pansy	0	0	0	0	3	4	1	1	4	5	1	1
Hesperiidae	Rice swift	0	1	0	0	1	1	0	0	1	2	1	0

Table 21: Seasonal distribution of butterflies according to families at site 1

Families	2022-2023				2023-2024				2024-2025			
	Monsoon	Post-Monsoon	Summer	Winter	Monsoon	Post-Monsoon	Summer	Winter	Monsoon	Post-Monsoon	Summer	Winter
Papilionoidea	2	5	0	0	4	8	1	0	4	8	0	0
Pieridae	17	34	13	12	33	45	26	13	35	50	26	14
Lycaenidae	3	10	2	2	18	34	9	2	14	34	9	2
Nymphalidae	29	51	17	7	50	73	30	17	61	87	32	17
Hesperiidae	0	1	0	0	1	1	0	0	1	2	1	0

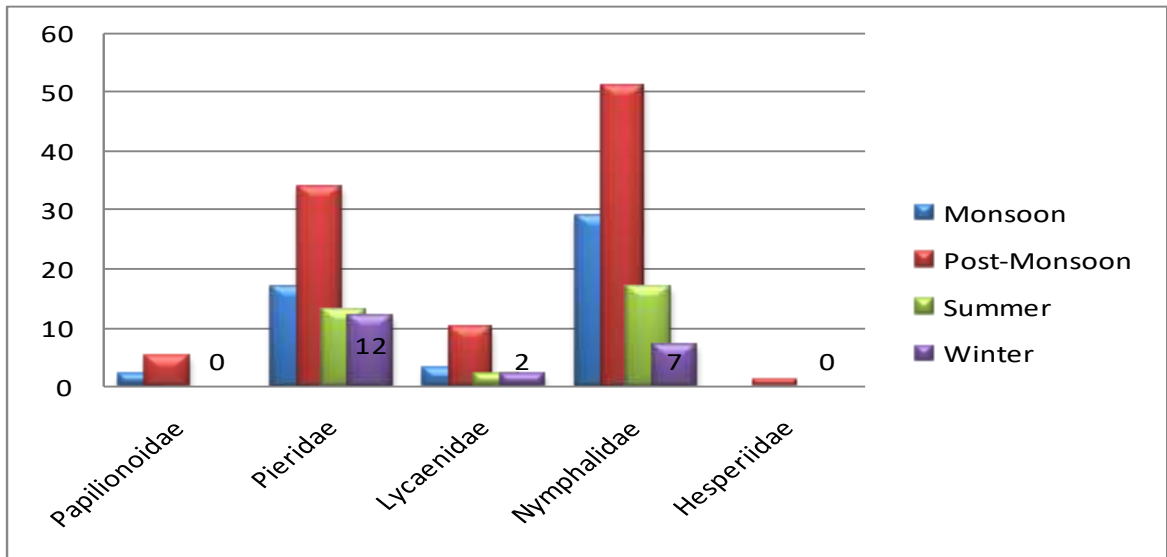


Fig 12: Seasonality of different families of butterflies at site 1 in the year March 2022-February 2023.

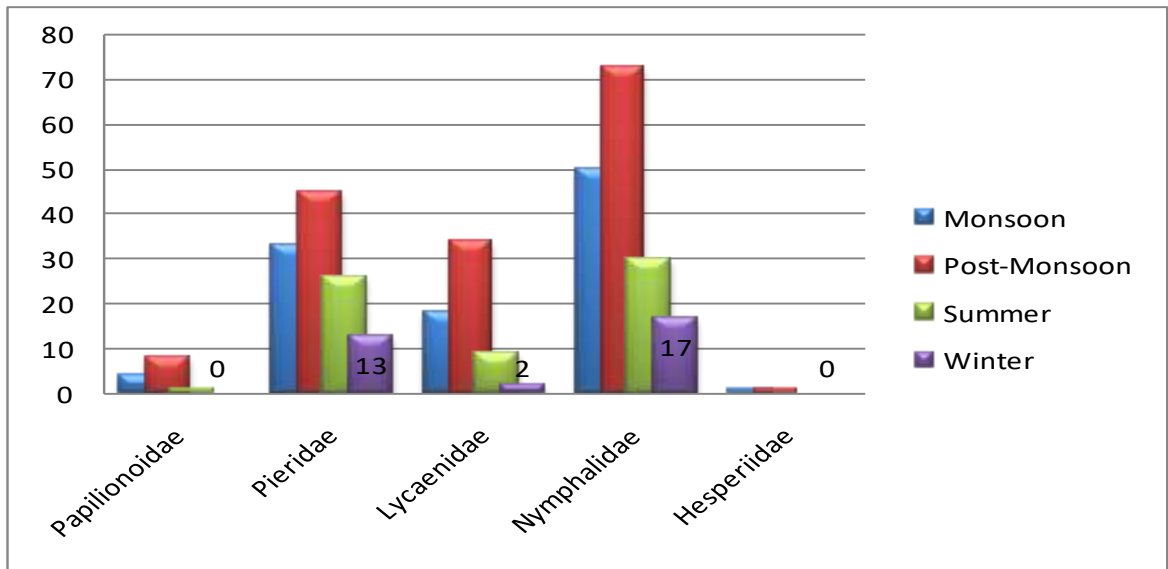


Fig 13: Seasonality of different families of butterflies at site 1 in the year March 2023-February 2024.

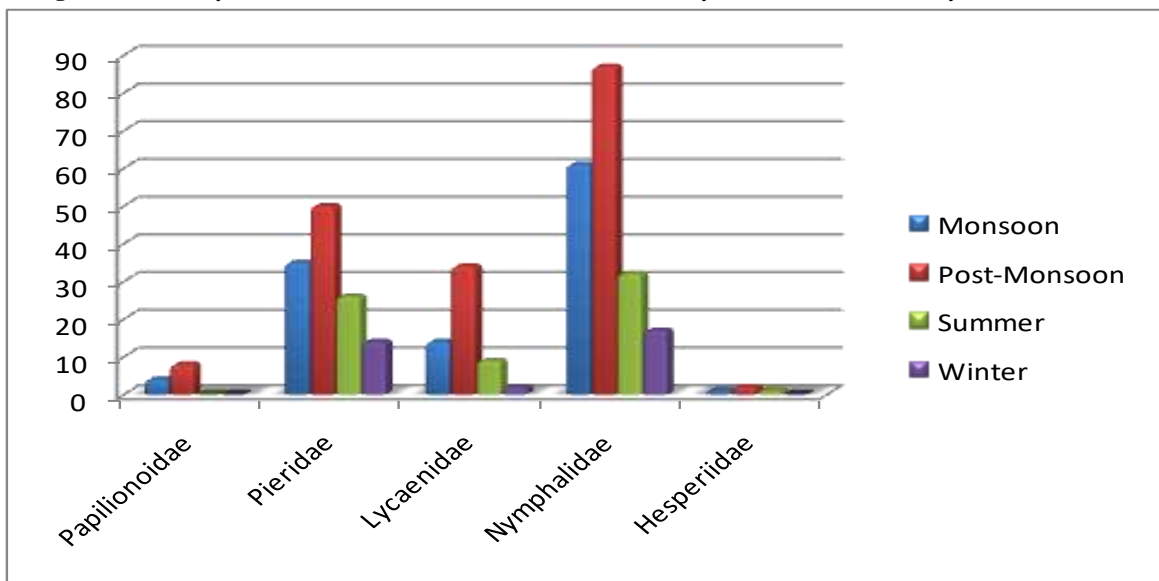


Fig 14: Seasonality of different families of butterflies at site 1 in the year March 2024-February 2025.

Table 22: Seasonality of different species of butterflies at site 2 across three years of study

Families	Species	2022-2023				2023-2024				2024-2025			
		Monsoon (July-Aug)	Post-Monsoon (Sept-Nov)	Summer (April-June)	Winter (Dec-March)	Monsoon (July-Aug)	Post-Monsoon (Sept-Nov)	Summer (April-June)	Winter (Dec-March)	Monsoon (July-Aug)	Post-Monsoon (Sept-Nov)	Summer (April-June)	Winter (Dec-March)
Pieridae (3)	Mottled emigrant	1	2	1	0	0	2	0	0	1	3	0	0
	Spotless grass yellow	5	19	2	0	4	8	2	0	5	11	3	1
	Common grass yellow	5	10	3	1	3	5	2	1	3	4	2	1
Lycaenidae (2)	Grass jewel	1	2	0	0	0	2	0	0	1	3	0	0
	Pale grass blue	15	30	4	1	4	8	3	2	4	7	3	2
Nymphalidae (6)	Blue pansy	0	1	0	0	0	1	0	0	1	3	0	0
	Plain tiger butterfly	10	22	8	2	2	4	2	0	3	5	2	0
	Lemon pansy	2	3	2	0	1	2	0	0	1	3	0	0
	Common tiger butterfly	10	23	2	0	5	10	3	2	7	13	3	2

	Grey pansy	1	1	1	0	2	3	1	0	3	5	1	0
	Danaid eggfly	0	1	0	0	1	1	0	0	1	3	0	0

Table 23: Seasonal distribution of butterflies according to families at site 2

Families	2022-2023				2023-2024				2024-2025			
	Monsoon	Post-Monsoon	Summer	Winter	Monsoon	Post-Monsoon	Summer	Winter	Monsoon	Post-Monsoon	Summer	Winter
Pieridae	11	31	6	1	7	15	4	1	9	18	5	2
Lycaenidae	16	32	4	1	4	10	3	2	5	10	3	2
Nymphalidae	23	51	13	2	11	21	6	2	16	32	6	2

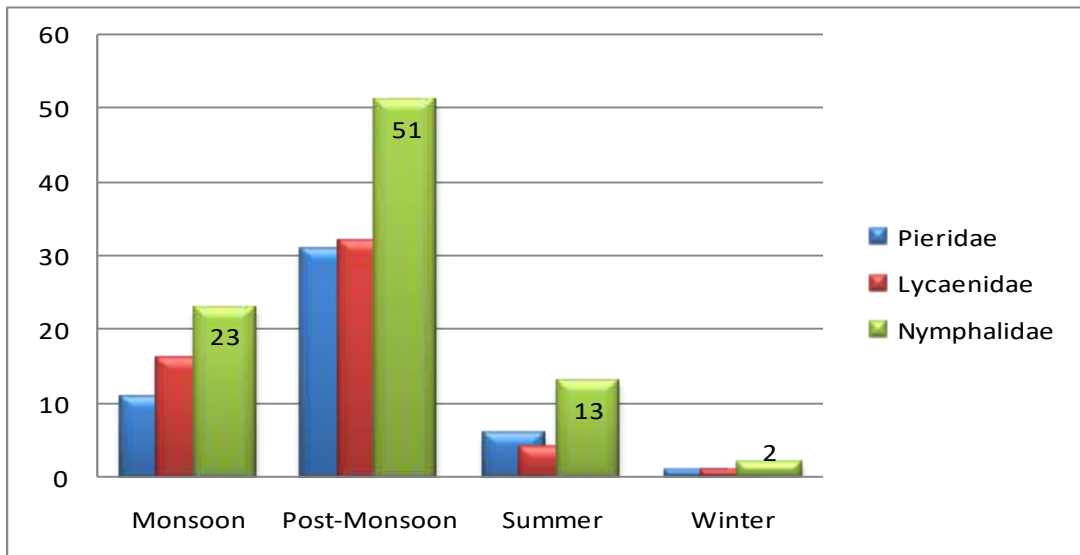


Fig 15: Seasonality of different species of butterflies at site 2 in the year March 2022-February 2023.

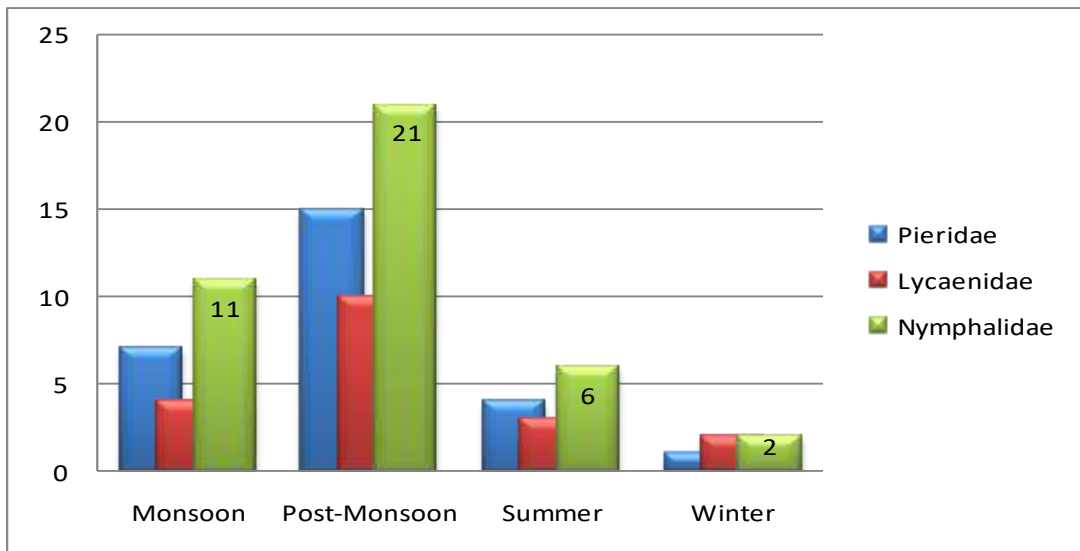


Fig 16: Seasonality of different species of butterflies at site 2 in the year March 2023-February 2024.

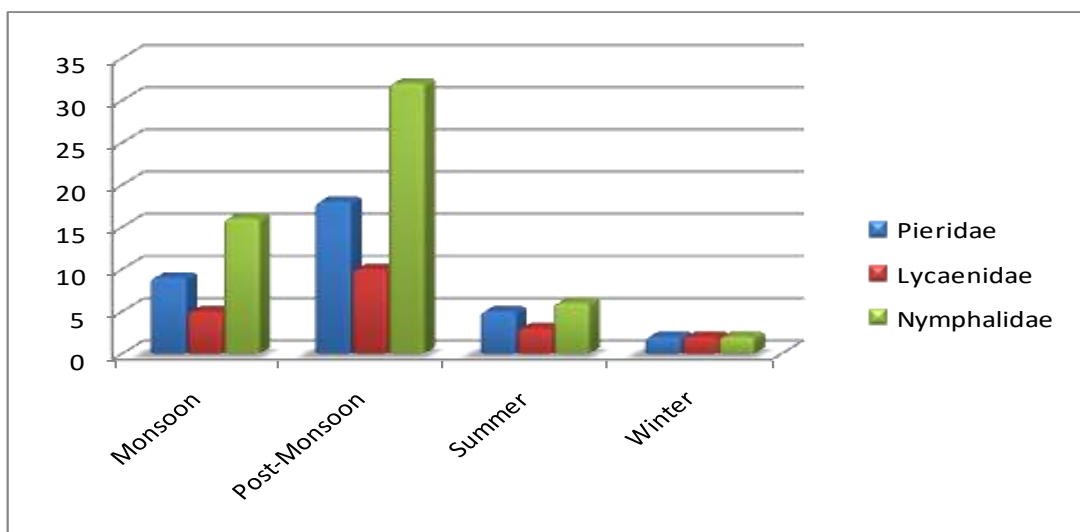


Fig 17: Seasonality of different species of butterflies at site 2 in the year March 2024-February 2025.

Table 24: Seasonality of different species of butterflies at site 3 across three years of study

Families	Species	2022-2023				2023-2024				2024-2025			
		Monsoon (July-Aug)	Post-Monsoon (Sept-Nov)	Summer (April-June)	Winter (Dec-March)	Monsoon (July-Aug)	Post-Monsoon (Sept-Nov)	Summer (April-June)	Winter (Dec-March)	Monsoon (July-Aug)	Post-Monsoon (Sept-Nov)	Summer (April-June)	Winter (Dec-March)
Pieridae	Spotless grass yellow	0	4	1	0	2	5	1	0	2	7	1	0
	Common grass yellow	1	3	0	0	1	2	0	0	1	4	0	0
Lycaenidae	Grass jewel	1	2	0	0	1	3	1	0	1	3	0	0
	Pale grass blue	1	2	0	0	1	1	0	0	3	6	0	0
Nymphalidae	Blue Pansy	0	1	0	0	1	2	0	0	1	3	0	0
	Plain tiger butterfly	1	3	1	0	1	3	1	0	2	6	1	0
	Common tiger butterfly	2	4	1	1	2	3	2	2	2	9	1	0
	Grey pansy	0	1	0	0	1	1	0	0	2	6	0	0

Table 25: Seasonal distribution of butterflies according to families at site 3

Families	2022-2023				2023-2024				2024-2025			
	Monsoon	Post-Monsoon	Summer	Winter	Monsoon	Post-Monsoon	Summer	Winter	Monsoon	Post-Monsoon	Summer	Winter
Pieridae	1	7	1	0	3	7	1	0	3	11	1	0
Lycaenidae	2	4	0	0	2	4	1	0	4	9	0	0
Nymphalidae	3	9	2	1	5	9	3	2	7	24	2	0

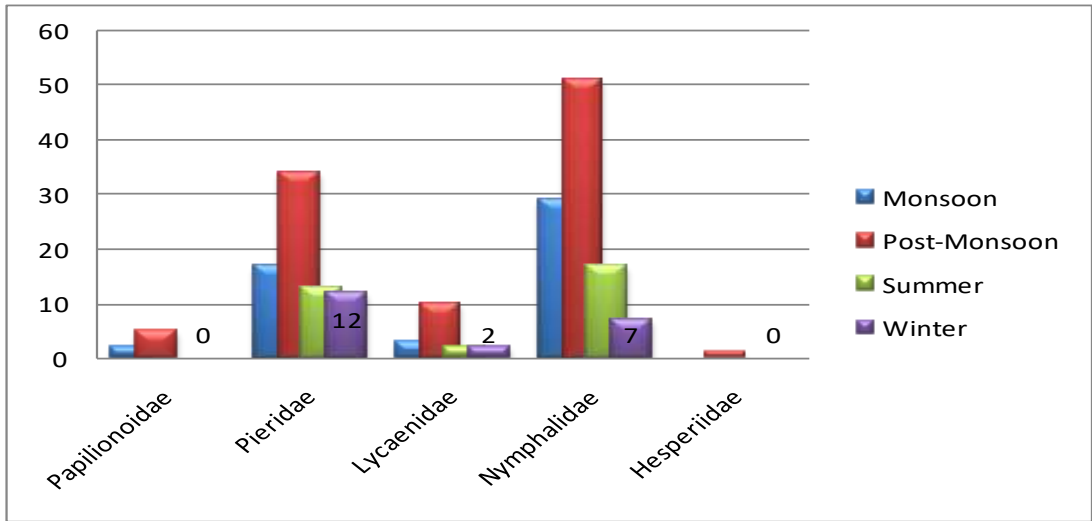


Fig 18: Seasonality of different families of butterflies at site 1 in the year March 2022-February 2023.

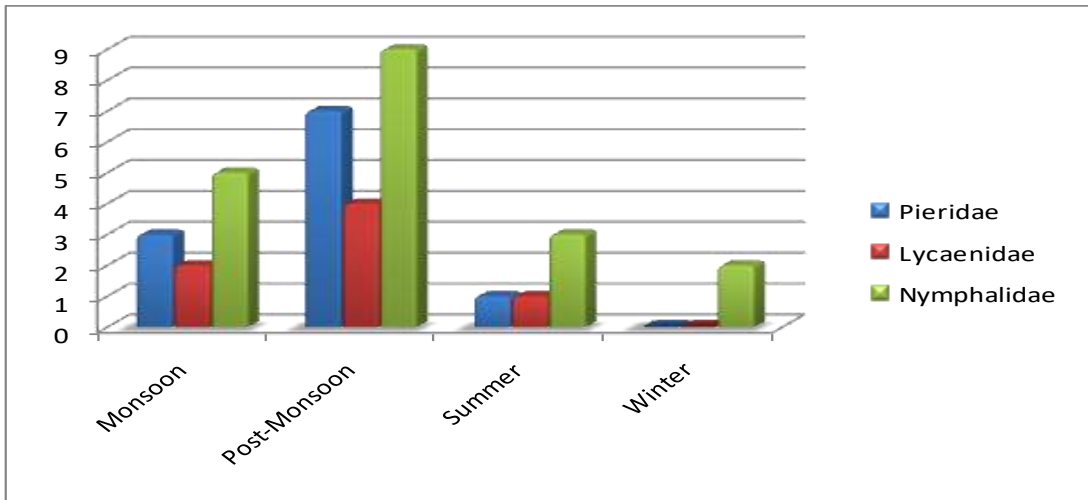


Fig 19: Seasonality of different families of butterflies at site 3 in the year March 2023-February 2024.

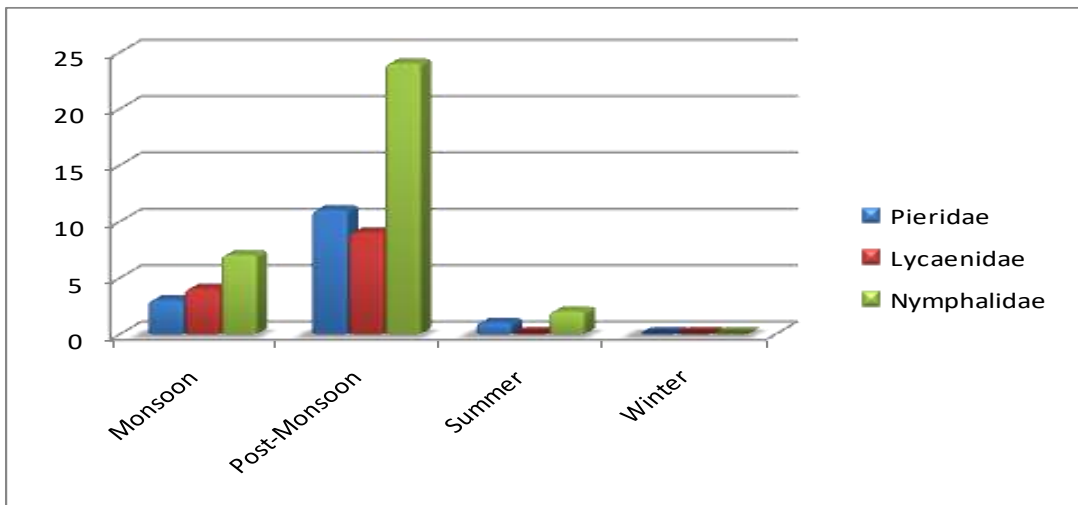


Fig 20: Seasonality of different families of butterflies at site 3 in the year March 2024-February 2025.

Table 26: Seasonality of different species of butterflies at site 4 across three years of study

Families	Species	2022-2023				2023-2024				2024-2025			
		Monsoon (July-Aug)	Post-Monsoon (Sept-Nov)	Summer (April-June)	Winter (Dec-March)	Monsoon (July-Aug)	Post-Monsoon (Sept-Nov)	Summer (April-June)	Winter (Dec-March)	Monsoon (July-Aug)	Post-Monsoon (Sept-Nov)	Summer (April-June)	Winter (Dec-March)
Papilionidae	Common jay	5	8	3	2	4	7	1	0	4	8	1	1
	Common rose swallowtail	3	5	2	1	1	5	0	0	1	5	1	0
	Common mormon swallowtail	5	7	3	1	3	8	0	0	3	7	0	0
	Lime swallowtail	3	5	2	1	3	4	2	1	6	12	1	0
Pieridae	Mottled emigrant	5	9	3	2	5	9	3	1	6	10	3	1
	Spotless grass yellow	12	26	11	8	13	20	9	3	15	22	9	3
	Common grass yellow	15	23	10	9	19	25	16	6	19	26	17	6
	Striped albatross	10	15	8	5	14	20	10	6	14	19	10	6
	Common gull	13	20	10	8	10	15	10	5	10	14	9	5

	Pioneer white	15	23	10	9	21	22	15	3	22	24	15	4
	Common jezebel	8	12	5	4	7	10	6	2	7	15	6	2
	White orange tip	6	16	4	0	12	21	10	1	13	21	10	2
	Common emigrant	14	19	10	5	21	25	11	4	22	27	12	4
Lycaenidae	Grass jewel	5	17	5	1	10	15	9	6	9	15	6	5
	Dark grass blue	5	8	4	0	10	15	8	5	11	15	9	5
	Striped pierrot	8	12	7	0	15	10	10	0	16	15	10	1
	Pale grass blue	3	10	2	1	22	22	12	0	22	23	12	2
	Forget-me-not	10	22	7	3	5	10	3	0	5	10	4	1
	Zebra blue	4	16	2	1	3	7	2	0	4	7	2	1
	Lime blue	5	23	3	1	5	7	3	0	7	9	3	1

Nymphalidae	Blue pansy	4	9	2	1	4	7	0	0	5	7	2	1
	Plain tiger butterfly	22	33	9	6	20	23	11	10	21	23	15	11
	Lemon pansy	10	14	4	2	15	19	9	3	10	18	9	3
	Tawny coster	11	18	10	1	12	14	10	6	13	20	10	6
	Common tiger butterfly	19	26	10	5	10	15	10	5	10	15	6	4
	Grey pansy	15	21	11	0	21	23	12	3	22	26	12	4
	Danaid eggfly	14	17	11	1	15	19	10	4	15	29	11	5
	Chocolate pansy	9	11	8	0	10	15	8	4	15	20	8	4
	Common castor butterfly	4	19	3	1	4	8	3	1	10	30	3	2
	Angled castor	5	11	3	2	6	6	0	0	6	6	2	1
	Common evening brown	7	12	5	1	9	9	6	2	9	9	6	2

	Peacock pansy	9	15	2	1	10	10	7	0	9	10	6	0
	Blue tiger	4	22	3	0	3	5	3	0	5	7	3	0
	Common leopard	8	12	3	0	4	9	1	0	4	9	2	1
	Common crow	5	26	3	0	6	9	2	1	7	10	2	1
	Great eggfly	11	20	2	0	15	21	9	3	15	21	9	4
Hesperiidae	Rice swift	1	1	0	0	2	4	0	0	2	5	0	0
	Indian palm bob	3	5	0	0	5	10	1	0	6	10	2	0

Table 27: Seasonal distribution of butterflies according to families at site 4

Families	2022-2023				2023-2024				2024-2025			
	Monsoon	Post-Monsoon	Summer	Winter	Monsoon	Post-Monsoon	Summer	Winter	Monsoon	Post-Monsoon	Summer	Winter
Papilionoidea	16	25	10	5	11	24	3	1	1	32	3	1
Pieridae	98	163	71	50	122	167	90	31	31	178	91	33
Lycaenidae	40	108	30	7	70	86	47	11	11	94	46	16
Nymphalidae	157	286	89	21	164	212	101	42	42	260	106	49
Hesperiidae	4	6	0	0	7	14	1	0	0	15	2	0

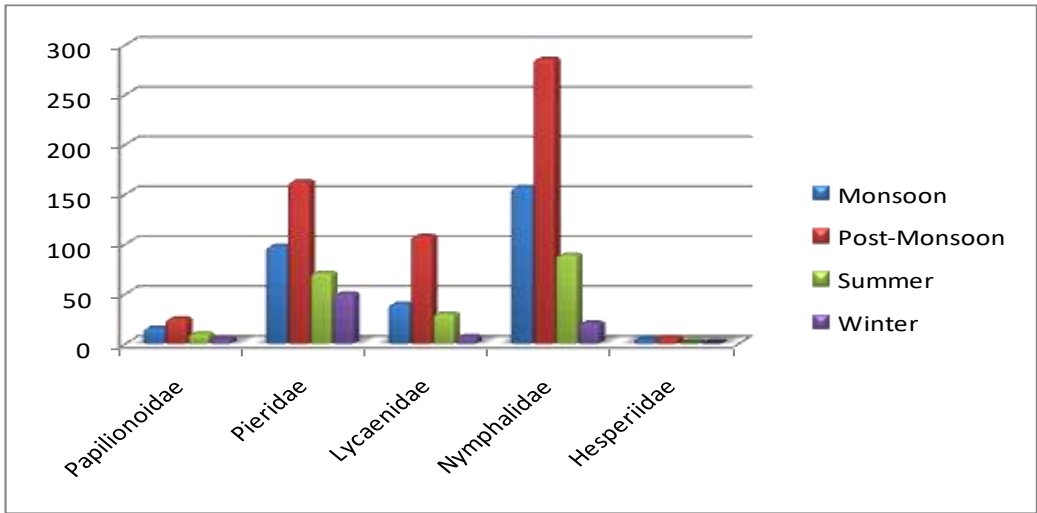


Fig 21: Seasonality of different families of butterflies at site 4 in the year March 2022-February 2023.

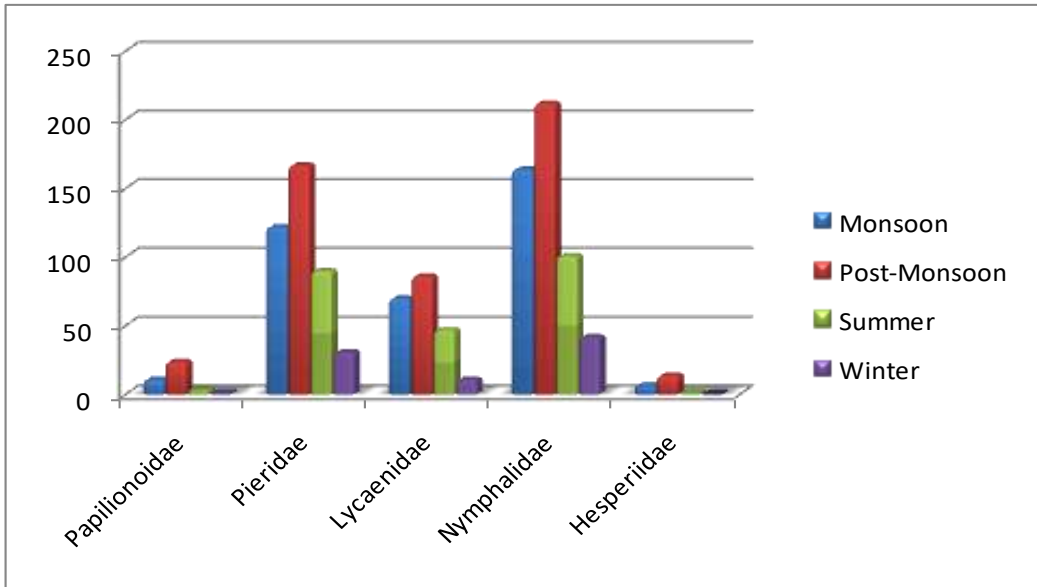


Fig 22: Seasonality of different families of butterflies at site 4 in the year March 2023-February 2024.

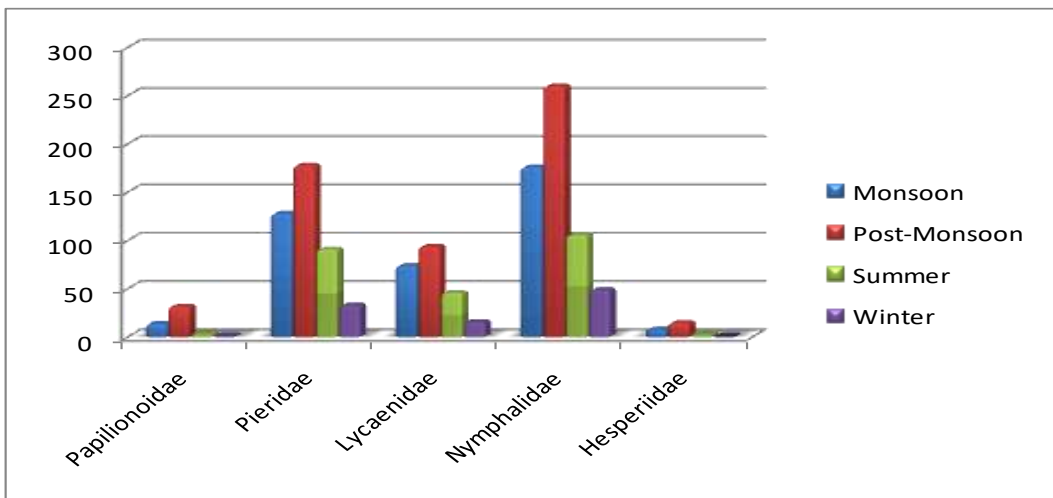


Fig 23: Seasonality of different families of butterflies at site 4 in the year March 2024-February 2025.

(F) Impact of pesticides on butterfly abundance

Butterflies serve as reliable bioindicators of agro-ecosystem health because their abundance and species composition are strongly influenced by vegetation cover, habitat quality and pesticides exposure. In the present study, the application of pesticides on vegetable crops and flowering plants was observed to have a direct as well as indirect influence on butterfly communities. Since pesticides alter host plant availability and can exert toxic effects on larvae and adults, their use is expected to impact both species richness and abundance of butterflies in the study area.

For this study of the impact of pesticide application on butterfly abundance two adjacent plots of land, each measuring 20 x 20 feet was selected, located near Kota, Rajasthan. The study was carried out for duration of three months (October, November and December). To assess the impact of pesticides use on butterfly abundance, one plot was treated with pesticides, while the other was maintained as control set of experiment without any pesticide application. These two lands were cultivated with a range of flowering plants and vegetable crops to stimulate a diverse agriculture environment. The selected plant species included marigold (*Tagetes erecta*), periwinkle (*Catharanthus roseus*), and vegetables such as red and green chili (*Capsicum annuum*), tomato (*Solanum lycopersicum*), brinjal (*Solanum melongena*), spinach (*Spinacia oleracea*), and cauliflower (*Brassica oleracea* var. *botrytis*). This setup allowed for a comparative analysis of butterfly abundance under treated and untreated conditions.

Vegetable crops and flowering plants were treated with pesticides in a rotational manner, where neem oil (Nimbecidine Azadiractin 300 PPM) was applied as a botanical formulation and Pevota™ Insect Control was used as a chemical pesticide. This sequential approach was adopted to manage pest populations effectively while attempting to minimize continuous chemical exposure. However, the combined use of these pesticides had a measurable influence on butterfly diversity and abundance. While neem oil exerted comparatively mild effects, the chemical pesticide treatments led to a greater reduction in larval survival and adult activity, thereby altering species richness and abundance patterns during the cropping season.



Plate 5: Experimental crops.

Pesticides used were-

1. Nimbicidine Azadirachtin 300 PPM- Nimbicidine is a neem-based biopesticide containing azadirachtin at 300 ppm, extracted from the seeds of *Azadirachta indica*. It functions mainly as an insect growth regulator, antifeedant, and repellent, interfering with the molting and reproductive processes of insect pests. Unlike synthetic chemicals, it is biodegradable, eco-friendly, and safe for beneficial organisms such as pollinators and natural enemies. It is widely used in vegetable and field crops for the management of sucking pests and early-stage caterpillars, and its effectiveness is enhanced when applied preventively or in the early phases of infestation. 2-3 ml per liter of water was used as foliar spray.
2. Pevota™ Insect Control (marketed by Chambal Fertilisers & Chemicals Ltd.)- Pevota™ is an insecticide marketed by Chambal Fertilisers & Chemicals Ltd., formulated with chlorantraniliprole, a modern anthranilic diamide molecule. It acts by activating ryanodine receptors in insect muscles, leading to paralysis and death of target pests, particularly lepidopteran larvae, fruit borers, stem borers, and leaf folders. The product is valued for its long residual activity, high selectivity, and comparatively safer profile for non-target organisms, including pollinators, when used as per recommendations. It is widely used on vegetable crops, 0.3 ml per liter of water was used as foliar spray.



Plate 6: Pesticides used in the experiment.

When the Neem oil is applied on the crops the larvae stop feeding, their growth and molting is interrupted and there is high mortality. There is minimally direct effect on the adult stage but the egg laying declines as the adult feeds on treated nectar. Sensitive species were immediately affected, there was decline in their abundance whereas the generalist species survived. So there is moderate reduction in species diversity.

When the Pevota™ Insect Control is applied as foliar spray there is reduction in species richness and abundance. Whereas in control set of experiment all butterfly species naturally occurring in the habitat are present.

The above experiment showed that the use of pesticides has a negative impact on butterfly diversity and abundance, as both organic and chemical applications contributed to a reduction in species richness and abundance, although the intensity of effect varied between them.

In the present investigation in the control set of experiment 9 species of butterflies were documented. Out of these 4 species (mottled emigrant, lime swallowtail, common grass yellow and common leopard) are sensitive species and 5 are generalist. In the current experiment pesticide treatment allowed survival of generalist species but sensitive species were eliminated. Generalist species survived with pesticide application but there was a decline in abundance. These observations align with findings from Van Deynze et al. (2024), who reported that insecticides were a major factor driving declines in butterfly populations in the U.S. Midwest, disproportionately affecting sensitive species while generalists were able to survive at lower numbers.

Table 28: Abundance of butterflies two areas one without pesticides and other with pesticides

	Species of butterflies	Number of individuals (Abundance) in control set of experiment	Number of individuals (Abundance) area treated with pesticides
1	Plain tiger butterfly	10	7
2	Common mormon swallowtail	5	3
3	Mottled emigrant	7	Nil
4	Common tiger butterfly	9	6
5	Lime swallowtail	2	Nil
6	Common emigrant	5	3
7	Common grass yellow	11	Nil
8	Common leopard	7	Nil
9	Common crow	3	2

Plate-7: FAMILY-PAPILIONIDAE



Graphium doson (common jay)



**Pachliopta aristolochiae
(common rose swallowtail)**



***Papilio polytes*
(common mormon)**



***Papilio demoleus*
(lime swallowtail)**

Plate-8: FAMILY-PIERIDAE



Catopsilia pyranthe
(Mottled emigrant)



Eurema laeta
(Spotless grass yellow)



Eurema hecabe
(Common grass yellow)



Appias libythea
(Striped albatross)



Cepora nerissa
(Common gull)



Belenois aurota
(Pioneer white)



Delias eucharis
(Common jezebel)



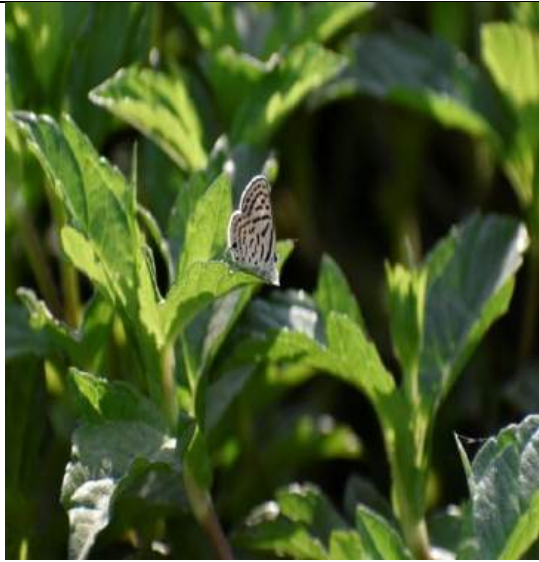



Ixias marianne
(White orange tip)



Catopsilia pomona
(Common emigrant butterfly)

Plate-9: FAMILY-LYCAENIDAE

	
<p><i>Chilades trochylus</i> (Grass jewel)</p>	<p><i>Zizzeria karsandra</i> (Dark grass blue)</p>
	
<p><i>Tarucus nara</i> (Striped pierrot)</p>	<p><i>Pseudozizeeria maha</i> (Pale grass blue)</p>



Catochrysops strabo
(Forget-me-not)







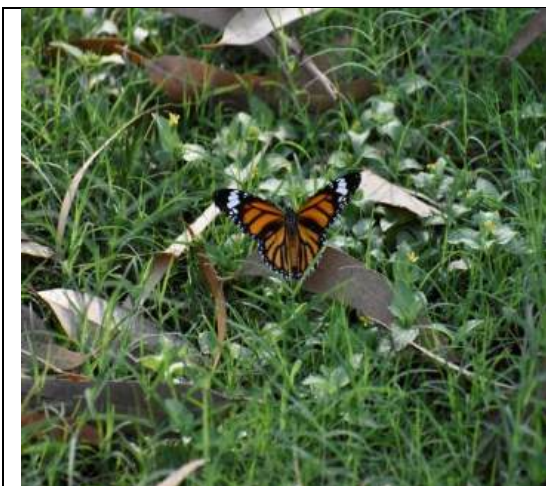
Leptotes plinius
(Zebra blue)



Chilades lajus
(Lime blue)

Plate-10: FAMILY-NYMPHALIDAE

	
<p><i>Junonia orithya</i> (Blue pansy)</p>	<p><i>Danaus chrysippus</i> (Plain tiger butterfly)</p>
	
<p><i>Junonia lemonias</i> (Lemon pansy)</p>	<p><i>Acraea terpsichore</i> (Tawny coster)</p>



Danaus genutia
(Common tiger butterfly)



Junonia atlites
(Grey pansy)



Hypolimnas misippus
(Danaid eggfly)



Junonia iphita
(Chocolate pansy)



Ariadne merione
(Common castor butterfly)



Melanitis leda
(Common evening brown)



Ariadne ariadne
(Angled castor)



Junonia almana
(Peacock pansy)



Tirumala limniace
(Blue tiger butterfly)



Phalanta phalantha
(Common leopard/spotted rustic)





	
<p style="text-align: center;"><i>Hypolimnastis bolina</i> (Great eggfly)</p>	<p style="text-align: center;"><i>Euploea core</i> (Common crow)</p>

Plate-11: FAMILY-HESPERIIDAE

	
<p style="text-align: center;"><i>Suastus gremius</i> (Indian palm bob)</p>	<p style="text-align: center;"><i>Borbo cinnara</i> (Rice swift)</p>

CHAPTER-5
CONCLUSION

CHAPTER-5

CONCLUSION

This study examined the diversity, abundance, richness, and evenness of butterfly in four different ecosystem of Kota and its adjoining villages, Rajasthan, India. The results showed significant variation in species composition and abundance across different habitats, with Nymphalidae consistently contributed the highest percentage of species composition across all sites and years, reflecting their adaptability and dominance in the study area. In contrast, Hesperidae showed the lowest percentage of species composition at Site 1 and Site 4, whereas Hesperidae and Papilionidae were completely absent at site 2 and 3, indicating their relative scarcity and sensitivity to habitat conditions.

The number of individuals at site 2 showed decrement in the second year of study, this was due to indiscriminate cutting of plants and trees. The observed decrease in individual numbers highlights the sensitivity of butterfly populations to habitat disturbance and emphasizes the critical role of vegetation in maintaining community abundance. Such findings indicate that unsustainable plant removal can directly impact population dynamics and overall ecosystem health.

Throughout the study period, the highest species richness was consistently recorded at Site 4, a relatively undisturbed natural area, whereas the low richness was observed in areas affected by indiscriminate cutting of plants and within agricultural land. These findings suggest that both vegetation removal, intensive pesticide use and monoculture pattern contribute to reduced butterfly species richness. Thus the overall result highlights the importance of preserving natural vegetation and maintaining habitat quality to support a diverse butterfly community.

The highest community evenness was observed in the natural area followed by high evenness value in agricultural land. This suggests that while natural area supported both high species richness and balanced species distribution, agricultural habitat with low species richness can also maintained a relatively

even distribution of butterfly species, this was due to the presence of a few resilient species that dominate in disturbed landscapes. Butterfly community evenness was relatively low in gardens and habitats near water bodies. This suggests that while these areas provide essential resources such as nectar and host plants, a few species tend to dominate the community, resulting in an uneven distribution. This indicates the importance of enhancing plant diversity and habitat quality even in resource-rich areas to maintain ecological balance.

The highest butterfly diversity was observed in natural area and garden, whereas lower diversity was recorded in agricultural land and habitats near water bodies. This pattern suggests that undisturbed natural habitats and well-vegetated gardens provide a variety of resources such as host and nectar plants, supporting a richer and more diverse butterfly community. In contrast, agricultural areas and riparian habitats may offer limited resources or be affected by disturbances, resulting in reduced species diversity. These findings emphasize the importance of habitat quality and vegetation management in maintaining butterfly biodiversity across different landscape types.

In the year 2022-2023 the most abundant butterfly in the overall study area was plain tiger butterfly. Whereas in the year 2023-2024 & 2024-2025 common grass yellow was the most abundant butterfly in the overall study area.

The abundance and diversity was higher during the post-monsoon season in the study area and was found lowest during winter season. In the post-monsoon season the host plants and nectar plants are available in abundance synchronizing with favourable temperature, sufficient rainfall and increased humidity. These conditions create a suitable environment for foraging, dispersal and breeding in turn supporting the highest butterfly dynamics. On the other hand during winter season low temperature and declined vegetation cover created unfavourable conditions for butterflies leading to low species richness and abundance. This decrease indicates that these adverse conditions act as a limiting factor for the sustenance of many species.

The study also highlighted the negative impact of pesticide use, which reduced species richness, abundance. The use of pesticides affected both larvae and adults. Sustainable management strategies, including integrated pest management (IPM), biopesticides and habitat conservation, are essential to balance agricultural productivity with butterfly conservation.

These findings underscore the importance of preserving natural habitats, establishing butterfly-friendly gardens, protecting riparian vegetation, and minimizing indiscriminate plant cutting. Overall, this research provides critical insights into butterfly community dynamics, demonstrating that maintaining habitat quality, reducing anthropogenic disturbances, and implementing biodiversity-friendly practices are key to sustaining butterfly populations and ecological health in the long term.

Butterfly diversity studies are valuable for guiding future ecological research and conservation. As sensitive bioindicators, butterflies can signal changes caused by habitat loss, climate shifts, and land-use practices. Linking such research with community awareness and sustainable farming can further promote ecological balance. This study adds to that effort by providing baseline data on species diversity, richness, evenness, abundance, and seasonal patterns. It highlights the need to maintain healthy habitats and limit harmful practices such as pesticide overuse and anthropogenic disturbances. Beyond their ecological role in pollination and food security, butterflies also carry cultural and aesthetic value, reminding us of our responsibility to protect biodiversity.

Summary

SUMMARY

Butterflies are one of the most fascinating group of insects, admired not only for their aesthetic beauty but also for their ecological importance. Belonging to the order *Lepidoptera*, they represent a highly diverse group distributed across almost all habitats, ranging from tropical forests and wetlands to agricultural fields and urban gardens. Globally, about 20,000 species of butterflies have been documented, of which India harbors more than 1,500 species, reflecting its rich faunal diversity (Kehimkar, 2008; Varshney & Smetacek, 2015).

Ecologically, butterflies play several crucial roles. They act as pollinators for many flowering plants, thereby contributing to ecosystem productivity and stability (Bonebrake et al., 2010). Their larval host specificity also makes them important for studying plant–herbivore interactions. In addition, butterflies form a vital part of the food web, serving as prey for birds, reptiles, spiders, and predatory insects (Kunte, 2000). Because of their high sensitivity to climatic and environmental changes, they are widely recognized as bioindicators of ecosystem health and habitat quality (Thomas, 2005; Kocher & Williams, 2000).

The diversity and abundance of butterflies in any habitat depend on multiple ecological factors such as altitude, vegetation type, seasonal variations, host and nectar plants availability (Sharma & Joshi, 2009). However, their population is under constant threat due to habitat destruction, fragmentation, intensive agriculture, pesticide use, and rapid urbanization (New, 1991; Kremen, 1992). Documenting butterfly diversity thus provides valuable insights into species richness, community composition, and habitat preferences, which are crucial for biodiversity monitoring and conservation.

In recent years, butterfly studies have gained significant attention in conservation biology. The establishment of butterfly gardens and habitat restoration projects has been recognized as an effective strategy for conserving butterfly species and raising public awareness (Arun, 2003; Bhardwaj et al., 2012). These initiatives not only safeguard butterflies but also support a wide range of other pollinators, contributing to ecosystem sustainability.

Therefore, the study of butterfly diversity holds both ecological and conservation significance. It provides baseline data essential for habitat management, long-term monitoring, and developing conservation policies. Understanding butterfly diversity is also critical in the context of climate change, as shifts in butterfly populations can act as early warning signals of broader environmental transformations (Parmesan, 2006).

The objective of the present study were to study the biodiversity and abundance of Lepidoptera (butterflies) in four different ecosystems of Kota and its adjoining viallges, Rajasthan, India. In the present investigation, the study was primarily focused on butterfly diversity, species richness, evenness, and abundance, along with an assessment of their seasonality. Furthermore, an experimental setup was designed to evaluate the impact of pesticide application on butterfly abundance, thereby highlighting the influence of agricultural practices on butterfly populations. This research examines the diversity of butterflies across four contrasting habitat types: natural landscape with least anthropogenic disturbance, managed garden spaces (urban), agricultural field used for crop production, and habitat situated near water body. Each of these ecosystems provides distinct ecological conditions that shape butterfly communities in different ways. By comparing these sites, the study aims to highlight how habitat characteristics and human activities influence species richness and distribution, thereby offering insights into the ways ecosystems either sustain or reduce biodiversity. The sampling was done by “Line Transect Method”. All the sites were visited at regular intervals. Butterflies were observed between 7 am to 11 am and in evening 4 pm to 6 pm. To identify the butterflies, they were caught using aerial net, photographed and then safely released back into the environment. Insects were photographed using Nikon Z611. In this study, different diversity indices were used to assess butterfly communities. These include the Shannon–Wiener index, Simpson’s index of diversity, Margalef’s richness index, Pielou’s evenness index, and Jaccard’s similarity and dissimilarity index. Together, these indices helped in understanding the patterns of diversity, richness, evenness, and similarity among butterfly species across different sites.

The insects were identified based on their wings color, pattern, shapes, sizes, with the help of entomological experts, available literature (online web resources- www.ifoundbutterflies.org, www.inaturalist.org, Butterflies of India by Arun Pratap Singh), standard field guides, catalogues and keys (Evans, 1927; Varshney and Smetacek, 2015; Kehimkar, 2016). All the scientific names follow Varshney RK & Smetacek P (2015). Data was analyzed using Microsoft Office Excel 2007 and past4.13 software.

The findings of the study are summarized below-

1. In the year 2022-2023, total of 1,612 individuals were recorded, followed by 1,692 individuals in the second year (2023-2024) and 1,894 individuals in the year 2024-2025. In a total 38 species belonging to 27 genera and 5 families of superfamily Papilionoidea were recorded in the period of three years. Throughout all the study period no change in species richness at site 4 (Kolipura- 38 species), site 2 (Abheda- 11 species) and site 3 (Bhopatpura- 8 species), whereas at site 1 (C.V garden) 19 species were reported in the first year and for the subsequent two years the species count reached upto 25 species

During the study period, in terms of species composition the least dominant family was Hesperidae at site 1 and site 4 whereas at site 2 (Abheda) the least dominant family in terms of species was Lycaenidae (18.18%) followed by Pieridae (27.27%). While at site 3, Lycaenidae (25%) and Pieridae (25%) showed the equal contribution in terms of species composition. Over the span of three years of study, the most dominant family in terms of species composition was Nymphalidae family.

2. At site 1 in the year 2022-2023, among the recorded butterfly families, Nymphalidae contributed the highest percentage of species composition (36.8%), followed by Pieridae and Lycaenidae (21% each) and Papilionidae (15.78%). Hesperidae contributed the least percentage of species (5.26%). Across the site 2, family Nymphalidae was the most speciose with species composition 54.54%, followed by Pieridae (27.27%) and Lycaenidae (18.18%).

Family Papilionidae & HesperIIDae were completely absent at site 2. In the study site 3, across the observed butterfly families, Nymphalidae contributed the highest in species composition (50%), family Pieridae and Lycaenidae contributed equally (25%). Family Papilionidae & HesperIIDae were completely absent at site 3. Within the site 4, family Nymphalidae contributed the highest to the species composition (42.10%), followed by Pieridae (23.68%) and Lycaenidae (18.42%). Papilionidae(10.52%) ranked next in terms of species composition. HesperIIDae contributed the least percentage of species (5.26%) which is similar to the site 1.

3. During 2023–2024 at site 1, the butterfly family Nymphalidae showed the highest species composition, accounting for 40%, while Lycaenidae ranked next with 24%. Family Papilionidae and Pieridae (16%) showed similar percentage of species composition. HesperIIDae contributed the least in terms of species composition (4%). Throughout the year 2023-2024 at site 2, site 3 and site 4, there was no change in the percentage species composition of all the families (same as observed during first year). Across the period 2024-2025, at all the sites the percentage of species composition of all the families remained unchanged (same as observed during second year). The consistency of species composition across families suggests that the area has reached a state of ecological stability, supporting the same set of species without new ones coming in or old ones disappearing.
4. During the study period, the number of species does not changed across different sites, apart from site 1 where the higher number of species were reported in the year 2023-2024 as compared to 2022-2023 year. This rise may be due to improved vegetation conditions, including the availability of host and nectar plants preferred by butterflies and reduction in human disturbances during this period likely created more favorable habitat conditions, which in turn supported higher species richness.
5. Throughout the study period, all the sites exhibited a progressive rise in the number of individuals. Only site 2 showed deviation from this trend where a reduction occurred in the 2023-2024 year but was followed by a subsequent

recovery in the 2024-2025 year. The number of individuals at site 2 in the year 2023-2024 decreased due to indiscriminate cutting of several plants & trees, and the natural vegetation of the area had been largely destroyed by increasing anthropogenic activities.

6. Over the two years (2022-2023, 2023-2024) increase in Margalef's index at site 1 was observed which indicates a notable improvement in the species richness, this is due to the habitat restoration and improved condition in the habitat. While in the year 2024-2025, slight decrease in Margalef's index indicates that species richness relative to the sample size has reduced.

At site 2, in the first two successive years (2022-2023, 2023-2024), Margalef's index showed a slight increase, but in the following year (2024-2025), it exhibited a minor decline. Again the Margalef's index was closer to as documented in the first year, indicating that the ecosystem is again overcoming the impact of habitat disturbances created by human activities. At site 2 in the year 2023-2024, the observed decreased number of individuals was documented following large-scale indiscriminate plant cutting. Results indicate that habitat degradation had a strong impact on the community. In the year 2024-2025, the number of individuals increased again at site 2, which indicates a positive ecological response.

During the first two years at site 3, Margalef's index showed only minor change, as the number of individuals increased slightly. In the 2024-2025 year a more pronounced decline was observed in Margalef's index as there was marked increase in the number of individuals. Since the total number of species remained unchanged, this reduction in the Margalef's index is due to changes in abundance. The result suggests that as the species richness was maintained, but the number of individuals was increased which indicates that community composition was constant because the habitat supported the same species over the time. Such a pattern indicates the quantitative expansion rather than the qualitative enrichment.

At site 4 species richness is still the highest and stable as compared to other sites, which is indicated by slight decrease in the Margalef's index value over the span of three years. So making the habitat an ecological hotspot for biodiversity. The steadiness in Margalef's index across the study period reflects that at the site 4 the species richness remained stable. This stability suggests the ecological persistence and stability of the prevailing community structure.

7. At site 1 and site 2, a significant increase in Pielou's index value was observed in the next two consecutive years (2023-2024, 2024-2025), which indicates that the community structure is becoming much more balanced than the year 2022-2023.

Pielou's index value of site 3 & 4 in all three years was very close to 1, which reflects that throughout the study period distribution of individuals was uniform across the species. Throughout the study period the highest evenness was observed at site 4, which indicates that the species are distributed more equally at the site. Therefore no single species is dominating in this habitat. Thus ecosystem at site 4 is stable and healthy ecosystem with minimal competition issues.

Similarly site 3 also has high evenness in the present investigation indicating good species balance in the ecosystem though slightly lower than site 4. However site 1 and site 2 have moderate evenness with some species being more dominant at these sites. This in turn reduces the evenness of the ecosystem. Such results are due to habitat disturbance and non-availability of host and nectar plants for other species. Lower evenness in the ecosystem contributes to the lower biodiversity as dominant species outcompete the other species.

8. The Shannon-Weiner Index varied between 1.883 to 3.506 in the study sites. The highest value of Shannon-Weiner Index was reported at site 4 and the lowest value was recorded at site 2. The Simpson index of diversity varied

between 0.824 to 0.968 in the study sites. The highest value of Simpson index of diversity was reported at site 4 and the lowest value was recorded at site 2.

A relatively higher Shannon or Simpson index of butterfly diversity at site 4 throughout the study period signifies that the butterfly community there is composed of a greater variety of species with a more even distribution of individuals. Second highest Shannon-Weiner index & Simpson index of diversity was observed at site 1, across all three years, indicating moderate diversity and reasonably diverse community having rich species distribution. Relatively low Shannon-Weiner index and Simpson index of diversity was reported at site 2 and site 3 in the present investigation, which indicates low diversity with fewer species being dominant. In the first two successive years there is increase in Shannon-Weiner and Simpson index of diversity at site 1 which indicates the higher species diversity compared to last year, which may be due to improved habitat conditions, better resource availability for the butterflies at site 1. In the third year as compared to second year, an increase value of Shannon-Weiner and Simpson index of diversity was observed in 2024–25 at site 1, although the total number of species remained unchanged. This suggests that the community structure is again becoming balanced with a more even distribution of individuals among the species in the course of time, rather than being dominated by a few species. Throughout the study period at site 2 and site 3 there is slight increase in Shannon-Weiner index and Simpson index of diversity although the number of species remained constant, this reflects improved species evenness, with individuals being distributed more uniformly across species.

It was observed in the survey data of the first two years that there is slight drop in Shannon-Weiner index and Simpson index of diversity at site 4 which suggests that high diversity is still maintained at site 4 but experiencing small changes in species distribution. Whereas in the year 2024-2025, the value of the Shannon-Wiener index increased, while the number of species remained consistent with the 2023-2024 year. This suggests a change in species

diversity or evenness without any significant change in species richness. Simpson index of diversity at site 4 remained constant in the year 2023-2024 & 2024-2025, while the total number of species did not change. This indicates that the relative abundance and distribution of species have remained consistent, reflecting a stable community structure.

9. At site 1 in the first year the community was dominated by spotless grass yellow and plain tiger butterfly whereas during the next couple of years common grass yellow appeared as the most abundant species. This shift in species dominance suggests the temporal fluctuation in community composition. This change may be due to the changes in habitat condition, availability of resources. Such trend suggest that the community is dynamic and responds to the environmental influences on species abundance.

During the initial year of observation at site 2 pale grass blue showed highest abundance however in the subsequent two years Common tiger butterfly became the most abundant species. The observed shifts in species dominance and distribution patterns suggest that species exhibit flexibility in response to ecological pressures such as climatic variations, resource availability, interspecific competition and habitat changes. These findings indicate that community structure is not fixed but dynamic. This dynamism strengthens the ecosystem's ability to absorb disturbances while still maintaining the overall integrity of the community.

Throughout the three years of study at site 3, Common tiger butterfly was recorded as the most abundant species. This indicates that, over time, the species composition remains largely unchanged, reflecting ecosystem stability. However, sustained dominance by a single species can lower evenness, as it disproportionately influences the overall community structure. In the first year at site 4, Plain tiger butterfly exhibited highest abundance whereas this dominance was replaced by Common grass yellow in the second year. While in the third year of study Plain tiger butterfly regained dominance. Such change in the composition

of community indicates that the ecosystem is not stable it is in continuous ecological pressure.

10. By using the Jaccard index beta diversity of the study site was evaluated.

Similarity in species composition between the sites is analyzed based on the presence or absence of species. Pair wise Jaccard similarity index value across the four different sites varied from 0.15 to 0.30. In the first year mean similarity was 0.23 and the computed average dissimilarity across the all site pairs was 0.77. This result indicates that 77% of the species composition was dissimilar between the sites. In the following two years mean similarity was 0.22 and the average dissimilarity across the all site pairs was 0.78. This suggests that 78% of the species composition was dissimilar between the sites. This indicates that the butterfly community is dynamic rather than stable.

11. In the present study gamma diversity of all the four sites was found to be 38 species, site 1 contributed 25 species, site 2 contributed 11 species, site 3 contributed 8 species and site 4 contributed 38 species.

12. Seasonal variation revealed that the abundance and diversity was higher during the post-monsoon season in the study area and was found lowest during winter season. In the post-monsoon season the host plants and nectar plants are available in abundance synchronizing with favorable temperature, sufficient rainfall and increased humidity. These conditions create a suitable environment for foraging, dispersal and breeding in turn supporting the highest butterfly dynamics. On the other hand during winter season low temperature and declined vegetation cover created unfavorable conditions for butterflies leading to low species richness and abundance. This decrease indicates that these adverse conditions act as a limiting factor for the sustenance of many species.

13. In this study, an experiment was designed to examine the impact of pesticides on butterfly abundance. For this investigation, two sets of crops were maintained: a control set, where crops were grown without the use of pesticides, and an experimental set, where pesticides were applied. In the control set of experiment 9 species of butterflies were documented. Out of

these 4 species (mottled emigrant, lime swallowtail, common grass yellow and common leopard) are sensitive species and 5 are generalist. In the current experiment pesticide treatment allowed survival of generalist species but sensitive species were eliminated. Generalist species survived with pesticide application but there was a decline in abundance.

Studies focusing on butterfly diversity and abundance in Kota are still inadequate. The present investigation, therefore, provides valuable baseline information on the diversity, seasonal patterns, and abundance of butterflies in four different ecosystems of Kota, Rajasthan, India. Such information is crucial, as butterflies not only serve as bioindicators of ecosystem health but also play an important role in pollination and maintaining ecological balance. By documenting species richness and assessing the effects of pesticides and seasonality, this work contributes to understanding local biodiversity and may serve as a reference for future conservation and management strategies in Kota. In the present study, it was noted that frequent disturbances arose from the indiscriminate cutting of plants by local communities. Such activities resulted in considerable habitat loss, which directly influenced insect biodiversity. To address this issue, it is essential for forest authorities to extend their monitoring efforts to small urban pockets as well, ensuring that unregulated vegetation removal is prevented. This is crucial, as the destruction of these habitats negatively affects the abundance, richness, and overall diversity of insect species.

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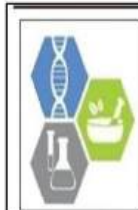
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Comparative study of diversity and seasonal abundance of butterflies in two different sites (Chatra Villas Garden and Abheda), Kota, Rajasthan, India

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Abstract

Butterflies are the most important “bioindicators” representing the overall health of the ecosystem (Pollard, 1991). Butterflies are dependent on different types of vegetation for their life. They are facing threats due to habitat loss and climate change that varies with seasons. Chatra villas garden is endowed with butterflies diversity due to lush green vegetation. Comparatively Abheda is lower in species richness and abundance of butterflies due to habitat loss and lesser variation in vegetation. Study of these bioindicators is crucial for patronage efforts, monitoring of ecosystem and overall understanding the health of the ecosystem. Number of species of butterflies is decreasing day by day due to increase use of pesticides, deforestation and climate change that ultimately results in loss of habitat of butterflies. The study was carried out in March 2022 to February 2023. For the sampling of butterflies “Line Transect Method” was used. The Microsoft excel was used for analyzing the data and for making the graphs. Maximum abundance (205) and species richness (19) was reported in Chatra villas garden. While in Abheda 191 individuals and 11 species of butterflies was reported. Shannon diversity index of Chatra villas garden ($H=2.288$) is more than the Abheda ($H=1.883$). The highest Simpson’s diversity index was at the Chatra villas garden ($D=0.8651$) than Abheda ($D=0.176$). The species richness Margalef’s index (R) of Chatra villas garden ($R=3.381$) was higher than the Abheda ($R=1.903$). Pielou’s evenness index (e) of Chatra villas garden was ($e=0.777$) lesser than Abheda ($e=0.785$). Nymphalidae family was the dominant family in both Chatra villas garden (36.84%) and in Abheda (54.54%). The least dominant family in Chatra villas garden was Hesperidae (5.26%) while in Abheda, Lycaenidae (18.18%) was the least dominant family. *Danaus chrysippus* (Plain tiger butterfly) and *Eurama laeta* (Spotless grass yellow) was the most dominant species in C.V garden. While in the Abheda *Pseudozizeerta maha* (Pale grass blue) was the most dominant species followed by *Danaus chrysippus*.

Keywords: Chatra villas garden, Abheda, diversity indices, species richness, relative dominance, seasonal abundance

Introduction

Butterflies are the most important “bioindicators” representing the overall health of the ecosystem (Pollard, 1991) [1]. Butterflies are dependent on different types of vegetation for their life. They are facing threats due to habitat loss and climate change that varies with seasons. As the butterfly population is declining day by day. So the study of their diversity, richness, evenness and abundance help us to track the population changes. Due to anthropogenic activities the shocks and the pressure on the ecosystem result into changes in environment in which living organisms (including butterflies) are unable to adapt. The species richness and kinds of butterflies also determined by habitat type. Therefore, observation of butterfly population helps in monitoring the environmental changes and the condition of habitats for biodiversity.

These Lepidopterans are able to detect the minute climatic variations. The diversity of species is affected by climatic changes such as temperature, rainfall patterns and harsh atmospheric conditions such as heat waves, persistent dry weather or persistent rainfall. The study of these bioindicators is crucial for patronage efforts, monitoring of ecosystem and overall understanding the health of ecosystem. The diversity of butterflies in the whole world is 18,000 species (IUCN, 2020).

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Out of that India accounts 1379 butterfly species (Das *et al.* 2023) [5].

Present study will help us to explore the diversity and seasonal abundance of two different sites. The result of present study will uncover the health of ecosystem and provide the baseline data which is focusing on the need to protect the habitat loss in order to conserve the biodiversity of butterflies.

Materials and Methods

Study area: For the biodiversity study of butterflies in Kota, two sites were selected- Chatra villas garden and Abhedha (near water body).

Site 1 Chatra villas garden is located at Nayapura Kota just adjacent to Kishore Sagar Talab. The geographical coordinates lies between latitude 25.20°N and longitude 75.85 °E (Fig 1). Area covered by C.V garden is 62.1 acres. The Chatra villas garden is enriched with unique flora and fauna. Different plant species present in Chatra villas garden are *Leucophyllum frutescens*, *Lantana camara*, *Niphar advena*, *Hamelia patens*, *Phlox*, *Crimm asiaticum*, *Langerstroemia indica*, *Parthenium hysterophorus*, *Azadirachta indica*, *Murraya paniculata*, *Tridax procumbens*, *Mangifera indica*, *Nelumbo nucifera*, *Acacia arabica*, *Calotropis procera*, *Hibiscus rosinensis*, *Psidium guajava* etc.



Fig 1: Map of C.V garden, Nayapura, Kota (Rajasthan).

Site 2 is Abhedha, which is situated near the Chambal river of Kota, Rajasthan. The geographical coordinates of Abhedha Mahal lies between latitude 25.20 °N and longitude 75.79 °E (Fig 2). Abhedha Mahal is located about 8 km from the main Kota city. This area is covered by grass and various plant

species like *Allamanda cathartica*, *Bougainvillea glabra*, *Calotropis procera*, *Hibiscus rosinensis*, *Lantana camara*, *Acacia catechu*, *Eichhornia crassipes*, *Ficus benghalensis*, *Parthenium hysterophorus* and *Azadirachta indica* etc.



Fig 2: Map of Abhedha (near the Chambal river of Kota, Rajasthan)

Method of sampling, collection of butterflies and identification: The sampling was done by "Line Transect Method" during March 2022 to February 2023. Regular visits and collections were done between 7 am to 11 am and in evening 4 pm to 6 pm with the help of Aerial net. Data was collected regularly every month and insects were photographed using Nikon Z611. The insects were identified based on their wings color, pattern, shapes, sizes, with the help of entomological experts, and available literature.

Statistical analysis

Alpha diversity is used and the data of identified species were analyzed for richness and abundance by using various diversity indices.

Shannon-Wiener diversity index (H')

It is alpha diversity index and it depends upon species richness and species evenness. High value of 'H' indicate greater diversity. Shannon-Wiener diversity index (Shannon, 1949) was calculated as-

$$H' = -\sum (p_i * \ln(p_i))$$

Where $p_i = S / N$, S = number of individuals of one species, N = total number of all individuals in the sample, \ln = logarithm to base e.

Simpson's Index (D)

Simpson's index denotes the alpha diversity of the selected area. It depends on both species richness and evenness. This index measures the probability that any two individuals drawn randomly from an infinitely large community will belong to same species. The Simpson's Index (Simpson, 1949) was calculated as-

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

Where, N = total number of individuals, n_i = number of individuals of i th species

The value of 'D' ranges from 0 to 1. Higher value of 'D' represents lower diversity
D= 0 represents infinite diversity, D=1 represents no diversity

Margalef's Index (D_{Mg})

This index is also an alpha diversity index and used as a simple measure of species richness (Magurran, 1988).

$$D_{Mg} = (S - 1) / \ln N$$

S = total number of species, N = total number of individuals in the sample

\ln = natural logarithm

Pielou's Evenness Index (e)

Pielou's index is an alpha diversity index that measures how evenly species are distributed in a community ((Pielou, 1969).

$$e = H' / \ln S$$

H' = Shannon - Wiener diversity index, S = total number of species in the sample

Relative abundance of butterfly families

The relative abundance of butterfly family was calculated by using dominance index.

$$\text{Relative abundance (family wise)} = ni \times 100 / N$$

Where n_i = number of butterflies in the 'i' th family, and N = the total number of butterflies in all the families collected in each habitat

Jaccard's Index (J)

This is another parameter to study beta diversity,

$$J = S_c / S_a + S_b + S_c$$

Where, S_a and S_b are the number of species unique to samples a and b respectively, and S_c is the number of species common to the samples.

Results

(A)- Species composition and distribution of butterfly species among families:

A total of 396 individuals of 19 species representing 15 genera, 5 families of superfamily Papilionoidea were recorded from both the sites during the study period. The higher number of species was reported from C.V garden (19 species) belonging to 5 families and 15 genera (Table 1a), whereas 11 species were reported from Abhedha belonging to 3 families and 6 genera (Table 1b). The least dominant family in term of species in C.V garden is Hesperidae (5.2%) while in Abhedha it is Lycaenidae (18.18%). In both C.V garden and Abhedha, Nymphalidae is having the highest percentage of species constituting 36.8% and 54.54% of total abundance respectively.

Butterflies were categorized on the basis of their abundance in C.V garden and in Abhedha as - VC- very common (> 20 sightings), C- common (3-20 sightings) and R- rare (1-2 sightings).

In C.V garden the most abundant species reported were *Eurema laeta* and *Danaus chrysippus*. *Pseudoteertha maha* is the most abundant species reported in Abhedha.

Table 1a: Checklist of butterflies recorded from site-I (C.V garden).

Family	Common name	Scientific name	Status
Papilionidae (3)	Common jay	<i>Graphium doson</i>	C
	Common rose swallowtail	<i>Pachlopta aristolochiae</i>	R
	Common mormon swallowtail	<i>Papilio polytes</i>	C
Pieridae (4)	Mottled emigrant	<i>Catopsilia pyranthe</i>	C
	Spotted grass yellow	<i>Eurema laeta</i>	VC
	Common grass yellow	<i>Eurema hecabe</i>	VC
	Striped albatross	<i>Appias libythea</i>	R
Lycaenidae (4)	Grass jewel	<i>Chilades trochylus</i>	C

	Dark grass blue	<i>Zizeeria karsandra</i>	R
	Striped pierrot	<i>Tarucus nara</i>	R
	Pale grass blue	<i>Pseudozizeeria maha</i>	C
Nymphalidae (7)	Blue pansy	<i>Junonia orithya</i>	C
	Plain tiger butterfly	<i>Danaus chrysippus</i>	VC
	Lemon pansy	<i>Junonia lemonias</i>	C
	Tawny coster	<i>Acraea terpsicore</i>	C
	Common tiger butterfly	<i>Danaus genutia</i>	VC
	Grey pansy	<i>Junonia alites</i>	C
	Danaid eggfly	<i>Hypolimnas misippus</i>	C
Hesperiidae (1)	Rice swift	<i>Borbo cinnara</i>	R

Table 1b: Checklist of butterflies recorded from site-II (Abhedha).

Family	Common name	Scientific Name	Status
Pieridae (3)	Mottled emigrant	<i>Catopsilia pyranthe</i>	C
	Spotless grass yellow	<i>Eurema laeta</i>	VC
	Common grass yellow	<i>Eurema hecabe</i>	C
Lycaenidae (2)	Grass jewel	<i>Chilades trochylus</i>	C
	Pale grass blue	<i>Pseudozizeeria maha</i>	VC
Nymphalidae (6)	Blue pansy	<i>Junonia orithya</i>	R
	Plain tiger butterfly	<i>Danaus chrysippus</i>	VC
	Lemon pansy	<i>Junonia lemonias</i>	C
	Common tiger butterfly	<i>Danaus genutia</i>	VC
	Grey pansy	<i>Junonia alites</i>	C

Table 1c: Comparison between site I and site II with respect to families, species and individuals.

Site	Number of families	Number of species	Number of individuals
S I	5	19	205
S II	3	11	191
Total			396

B). Species diversity, richness and abundance

Alpha diversity

The study of alpha diversity of particular population is a combination of species richness and species evenness.

At site I, 5 families with 15 genera and 19 species were recorded. Family Nymphalidae constituted 37% of total butterfly population, family Pieridae and Lycaenidae constituted 21%, family Papilionidae constituted 16% and family Hesperiidae constituted 5% of the total butterfly population at site I. The C.V garden showed the highest Shannon-Weiner diversity index (2.288) and the highest Simpson index of diversity (0.865).

At site II, 3 families with 6 genera and 11 species were recorded. Family Nymphalidae constituted 54.54% of total butterfly population, family Pieridae constituted 27.27% and family Lycaenidae constituted 18.18% of the total butterfly population at site II.

Shannon-Weiner diversity index of Abhedha is 1.883 and the Simpson diversity index of diversity is 0.824.

Site I was found to be more abundant and diverse as compared to site II. Family Hesperiidae is least abundant at site I, whereas family Hesperiidae was not recorded from the site II.

Butterfly population in relation to time of day was more abundant in morning time (7.00 - 11.00 AM) over the evening time (4.00 - 6.00 PM).

The Pielou's index (e) of site I was (0.777) lower than the site 2 (0.785). The higher value of Pielou's index at site II indicates that species are more evenly distributed at site II as compared to site I.

At site I Nymphalidae is the most dominant group, followed by Pieridae, Lycaenidae, Papilionidae. Family Hesperiidae is the least dominant group in the C.V garden.

At site II, Nymphalidae is the most dominant group like site I, followed by Lycaenidae. Family Pieridae represent the least dominant group of site II (Table 2).

Table 2: Comparison of butterfly diversity indices in site 1 & site 2.

Site	Margalef's Index (R)	Pielou's Index (e)	Simpson Index of Diversity (1-D)	Shannon Index (H)
1	3.381	0.777	0.865	2.288
2	1.903	0.785	0.824	1.883

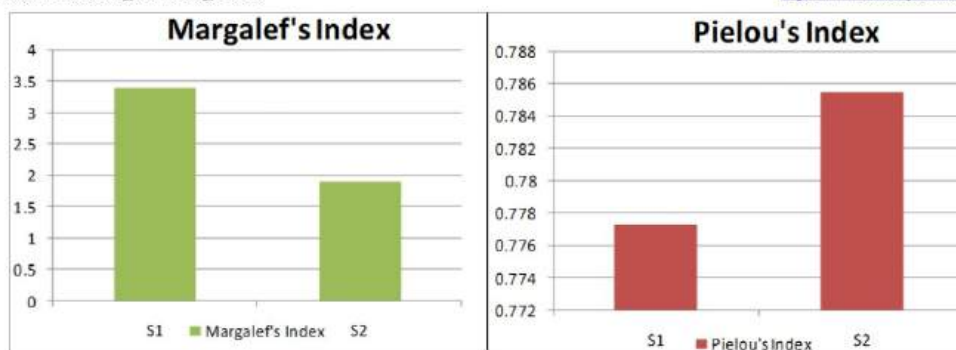


Fig 3a & 3b: Comparison of Margalef's index (species richness) and Pielou's index (species evenness) of site I & site II.

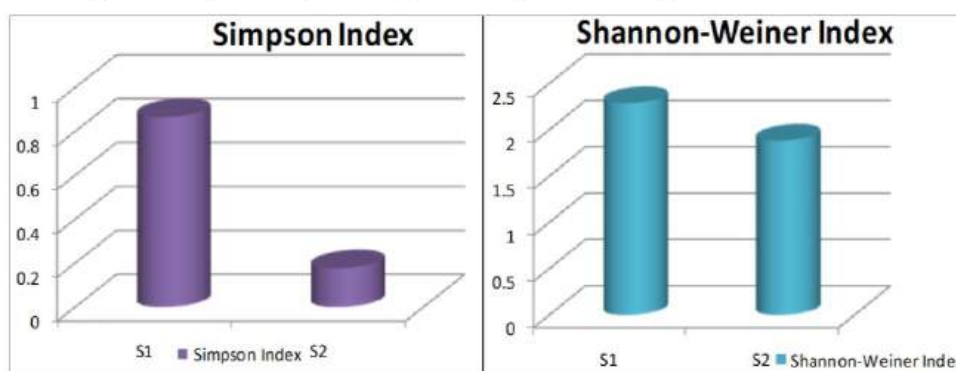


Fig 4a & 4b: Comparison of Simpson's index and Shannon-Weiner index of site I & site II.

Beta diversity: It is species diversity between two adjacent ecosystems and is measured by comparing the number of species unique to each ecosystem.

Jaccard's Index is used to calculate beta diversity. The Jaccard's index of S_1-S_2 is 0.27.

Gamma diversity

Gamma diversity describes the overall species diversity across communities within a larger geographical area.

In site I & site II, 396 individuals of butterflies were sampled belonging to 5 families & 19 species.

(C). Seasonal distribution and abundance of butterflies species among families

(1) Site-I

In terms of species composition at site I in Monsoon season family Nymphalidae showed highest species composition (53.8%) in comparison to other families. Family Lycaenidae showed lowest composition (7.6%), family Hesperidae was totally absent from the site I in Monsoon season. Species composition of family Papilionidae was 15.3% and species composition of family Pieridae was found 23% in Monsoon season.

In Post-Monsoon season family Nymphalidae showed highest species composition (36.8%) followed by family Pieridae (21%) and Lycaenidae (21%) and the lowest species composition was showed by Hesperidae (5.2%). Species

composition of family Papilionidae in Post-Monsoon season was 15.7%.

In winter season family Nymphalidae and Pieridae showed the highest species composition (42.8%) followed by Lycaenidae (14.2%). While family Papilionidae and Hesperidae were completely absent in winter season at Site I. Family Nymphalidae (63.6%) showed highest species composition in summer season followed by Pieridae (27.2%) and Lycaenidae (9%) while family Papilionidae and Hesperidae was completely absent in summer season at site I. In terms of species composition family Nymphalidae showed highest composition 63.6% in summer season and least in Post-Monsoon season. Similarly family Papilionidae represented its highest composition in winter season and least in the Post-Monsoon season.

Family Pieridae showed highest composition (42.8%) in winter season and least composition in Post-Monsoon season. Lycaenidae was highest (21%) in Post-Monsoon season, followed by winter season (14.2%), Monsoon season (7.6%) and least composition was in summer season (9%). Family Hesperidae showed its presence only in Post-Monsoon season.

(2) Site-II

In terms of species composition at site II in Monsoon season family Nymphalidae showed highest composition (44.4%) in comparison to other families. Family Pieridae showed

(33.3%) second highest species composition in Monsoon season followed by Lycaenidae (22.2%).

In Post-Monsoon season family Nymphalidae showed highest species composition (54.5%) followed by Pieridae (27.2%) and Lycaenidae (18.1%). In summer season Nymphalidae family showed highest species composition (50%) followed by Pieridae (37.5%) and Lycaenidae (12.5%).

In winter season, all the families (Pieridae, Lycaenidae and Nymphalidae) showed equal species composition (33.3%)

In terms of species composition, family Nymphalidae showed highest composition in Post-Monsoon season (54.4%) and least in winter season (33.3%).

Family Lycaenidae showed highest composition in winter season (33.3%) and least in summer season (12.5%). While Pieridae showed highest species composition in summer season (37.5%) and least in Post-Monsoon season (27.2%).

In terms of abundance all the families in both the sites were at their peak in Post-Monsoon season, followed by Monsoon, summer and winter season respectively (Table 3).

Table 3: Seasonal abundance of butterflies in site I & site II.

S. No.	Families	Abundant in season	
		Site-I	Site-II
1	Papilionidae	Post-Monsoon	-
2	Pieridae	Post-Monsoon	Post-Monsoon
3	Lycaenidae	Post-Monsoon	Post-Monsoon
4	Nymphalidae	Post-Monsoon	Post-Monsoon
5	Hesperiidae	Post-Monsoon	-

Table 4: Families showing highest abundance in all four seasons in site I & site II.

Site	Winter (Dec-March)	Summer (April-June)	Monsoon (July-Sept)	Post-Monsoon (Oct-Nov)
I	Pieridae	Nymphalidae	Nymphalidae	Nymphalidae
II	Nymphalidae	Nymphalidae	Nymphalidae	Nymphalidae

Discussion

The analysis of the results of present investigation showed that butterfly composition from both the habitats spread across 5 families, 15 genera and 19 species which is a indicator of rich biodiversity.

The biodiversity of butterflies at Abhedha is low as compared to C.V garden due to less variation in vegetation. The proper maintenance of natural habitat of Abhedha may be affected by anthropogenic activities.

In C.V garden the high diversity and richness of butterfly species was observed, which may be due to the availability of nectar and host plants of butterflies. This result favors the statement of Sreekumar and Balakrishnan (2001a) [35] said that prevalence of butterfly species at a particular habitat depends on a wide range of factors, of which the availability of the food is the most important.

In general the highest diversity of butterfly species are found in those areas which provide the large number of host plants. Results of present study are supported by results of Krauss *et al.* 2003 [13] which says species number of all the butterflies increase significantly with increasing diversity of the surrounding landscape.

The higher Shannon-Weiner index (2.288) and the higher Simpson index (0.865) of site I indicates that site I is more diverse than site II regarding the species of butterflies.

The results of present study agree with the findings of Sayeswara (2018) [31] who recorded higher percentage of species of butterfly from Nymphalidae family (44.4%), followed by Papilionidae (22.2%), Lycaenidae having (8.33%) and Hesperiidae family with least percentage of species of butterflies in the study area.

Both in C.V garden and Abhedha the Nymphalidae showed the highest species richness and abundance. The dominance of Nymphalidae can be due to polyphagous habit that helped them to live in all habitats (Sreekumar and Balakrishnan, 2001b) [36] which comprised the largest family of butterflies.

In terms of abundance in Abhedha the Lycaenidae family showed second highest abundance. The possible reason could be as the Lycaenidae family known to adopt various climates

and feeding on a variety of larval food plants (Kunte, 2001) [17]. Rich diversity of butterflies especially the Nymphalidae and Lycaenidae indicates a varied assemblage of floral species.

The higher number of Pieridae and Lycaenidae is supported by studies of Bernard who reported that that these two families can be seen almost everywhere. In C.V garden the Pieridae showed the second highest abundance. Pieridae are sun lovers seen basking in sun with wings partially open (Kehimkar, 2008) [10]. The possible reason for the abundance of Pieridae family in C.V garden is the presence of supporting habitat.

In the present study family Hesperiidae was recorded minimally at site I and was absent from the site II. This result favors the statement of Ombugadu *et al.* (2021) [21]. The reason for the lowest species richness and abundance showed by Hesperiidae family may be their flight period (early morning hours at dawn and dusk, Kehimkar, 2008) [10].

At site II the possible reason for the non availability of Hesperiidae family could be absence of supporting habitat and the time of study (7 am to 11 am and evening 4 pm to 6 pm).

Site I was found to be more abundant and diverse due to low level of anthropogenic activities like construction and habitat loss. Higher abundance and diversity in the C.V garden is because this site provides wider food and shelter resources for the butterflies whereas lesser abundance and diversity at Abhedha is due to the minimal availability of required vegetation. As the butterfly larval stages are plant specific, so a little disturbance to the abundance of required plants could have a negative impact on the population. Findings of present study is supported by Hill *et al.* 2003 [7] who reported great abundance of butterfly species in less disturbed habitats.

In C.V garden the highest species richness and abundance is showed in Post-Monsoon season especially in the month of September. This may be due to increase in new vegetation, flowering plants after rainy season.

The factors supporting the increase in vegetation are optimum temperature, light and rainfall indirectly supporting their abundance. The present result indicates that the abundance

and richness of butterflies was changed with the abundance and richness of plant species (Mukherjee *et al.* 2019) [19].

From December onwards there is gradual decline in abundance of butterflies both in C.V garden and Abhedra. This may be due to the least favorable weather which results in the loss of water, nectar and fresh vegetation.

Therefore, this variation of butterfly diversity in different seasons indicates that the abiotic factors such as rainfall, temperature and humidity played a vital role in influencing the distribution and abundance of butterflies. The results of present finding are supported by the study of Shubhalakshmi and Chaturvedi, 1999; Hill *et al.* 2003 [34, 7].

Conclusion: The analysis of results of present study clearly indicates that any change in the landscape directly affects the diversity and abundance of butterflies. Impact of land use change and habitat loss affects the biodiversity of butterflies. Many butterfly larval stages are plant specific, a little disturbance to the abundance of such plants could have a resultant negative effect on the population.

If the maintenance of gardens and landscaping are meticulously planned, the diversity of butterflies will definitely increase providing a rich area for butterfly conservation.

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Assessment of butterfly biodiversity across four different habitats of Kota, Rajasthan, India

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Abstract

Pollinating insects have been undergoing a decline in occurrence, abundance and diversity in many parts of the world (Ollerton *et al.*, 2014; Potts *et al.*, 2016) [25, 31]. Out of all the pollinating insects butterflies are the most important ones acting as “bioindicators”. As the butterflies are performing the critical ecosystem service so the decline in their diversity is a matter of concern. Study area Kolipura with low level of anthropogenic activities showed the highest diversity and richness of butterfly species. The study was carried out in the year 2022-2023 and 2023-2024. For the sampling of butterflies “Line Transect Method” was used. In both the year’s maximum abundance (1186, 1204) and species richness (38) was reported at site 4 (Kolipura). At site 4 the highest value of Shannon-Weiner Index and Simpson diversity index was reported in both the years followed by site 1 (Chatra Villas Garden), followed by site 3 (Bhopatpura) and lowest value of Shannon-Weiner Index and Simpson diversity index was reported at site 2 (Abhedra) in both the years. The highest species richness was observed at site 4 followed by site 1, site 3 and site 2 in the year 2022-2023. The order of species richness among the sites changed in the following year (site4>site1>site2>site3). This change happened because if S is high, but N is even higher, it causes the Margalef’s index to decrease. In the year 2022-2023, the highest species evenness was seen at site 4 followed by site 3, site 2 and site 1. While in the next year, the order changed to (site4>site3>site1>site2) this. Site 1, moved from 4th to 3rd indicates improved evenness overtaking site 2, this shows positive ecological change and reduced dominance of few species. Site 2, dropped from 3rd to 4th indicates that despite an increase in its evenness value, other sites (especially site 1) improved more, resulting in a relative drop in rank indicating slower or less effective improvement. Nymphalidae family was the most dominant family at all the four sites. The least dominant family at site 1 and site 4 was Hesperidae family while this family is altogether absent at site 2 and site 3. At site 1 in the first years the most abundant species reported were *Eurema laeta* and *Danaus chrysippus* while in the year 2023-2024 the most abundant species was *Eurema hecabe*. At site 2 *Pseudozizeeria maha* was the most abundant species reported in the year 2022-23, whereas in the year 2023-24 at site 2, *Danaus genutia* was the most abundant species reported. At site 4, *Danaus chrysippus* and *Eurema hecabe* was the most abundant species in the year 2022-23 and 2023-24 respectively. This shift in abundance indicates a possible change in habitat conditions, resources availability, or climatic factor that favored at site 2 *Danaus genutia* and *Eurema hecabe* at site 4 in the following year. It highlights the dynamic nature of butterfly populations and their sensitivity to environmental changes. The decline in host and nectar plants for *Danaus genutia* causing its population to decrease. At site 3, *Danaus genutia* was the most abundant species reported in both the years.

Keywords: Diversity indices, species richness, species evenness, relative abundance, relative dominance, butterfly, Kota

Introduction

Butterflies are the most studied insect group in the world. But a lot of changes are being seen in the diversity of butterflies and there are many reasons of it. Factors which are negatively impacting the diversity of butterflies are Urbanization and Pesticides used in the agriculture practices. The diversity of wild flora and many cultivated crops is maintained by the essential ecosystem service called pollination. The decline in pollinators is alarming as it raises questions regarding food security and stability of ecosystem function (Potts *et al.*, 2010) [30]. Several anthropogenic drivers are threatening the abundance, diversity and health of wild and managed pollinators, and the pollination service they provide to wild plants and crops (Vanbergen, & Insect Pollinators Initiative, 2013). Intensive agriculture activities,

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indiscriminate use of herbicides and insecticides, ground burning and monoculture farming is adversely affecting the diversity of butterflies. The drivers for the decline in insect pollinators worldwide include habitat transformation or fragmentation (Kennedy *et al.*, 2013) [11], loss of diversity and abundance of floral resources (Kremen *et al.*, 2007) [12], inappropriate use of pesticides (Petts *et al.*, 2013) [28] and climate change (Schweiger *et al.*, 2010) [38]. Around 95% individuals of butterflies are dying due to parasitic infestation, predators and parasitoids attack, habitat loss and pesticides-insecticides poisoning in agriculture ecosystems before attaining their adulthood. The natural area without or less anthropogenic activities is providing the best habitat for butterflies to adapt, whereas in areas with significant human interference butterflies are generally unable to adapt to the surrounding environment. Hence, assessing the biodiversity of butterfly populations greatly aids in monitoring and measuring environmental changes.

Plan of restoration of biodiversity and development of management strategies can be done in future with the help of present investigation in order to ensure the diversity of butterflies and the benefits provided by them. So the results of present study will uncover the health of ecosystem and provide the baseline data which is focusing on the need to conserve the ecosystem for the Lepidoptera's biodiversity.

Materials Methods: Study area: Site 1 Chatra vilas garden is located at Nayapura Kota just adjacent to Kishore Sagar Talab. The geographical coordinates lies between latitude 25.2012° north and longitude 75.8566° east. Area covered by C.V garden is 62.1 acres. The Chatra villas garden is enriched with unique flora and fauna. Different plant species present in Chatra villas garden are *Leucophyllum frutescens*, *Lantana camara*, *Niphar advena*, *Hamelia patens*, *Phlox*, *Crimin asiaticum*, *Langerstroemia indica*, *Parthenium hysterophorus*, *Azadirachta indica*, *Murraya paniculata*, *Tridax Procumbens*, *Mangifera indica*, *Nelumbo nucifera*, *Acacia arabica*, *Calotropis procera*, *Hibiscus rosa-sinensis*, *Psidium guajava* etc.

Site 2 is Abhedha, which is situated near the Chambal river of Kota, Rajasthan. The geographical coordinates of Abhedha Mahal lies between latitude 25.2000° North and longitude 75.7905° east. Abhedha Mahal is located about 8 Kms from the main Kota city. This area is covered by grass and various plant species like *Allamanda cathartica*, *Bougainvillea glabra*, *Calotropis procera*, *Hibiscus rosa-sinensis*, *Lantana camara*, *Acacia catechu*, *Eicchornia crassipes*, *Ficus benghalensis*, *Parthenium hysterophorus* and *Azadirachta indica* etc.

Site 3 is Bhopatpura Village which is a small Village/hamlet in Talera Tehsil in Bundi District of Rajasthan State, India. It comes under Bhopatpura Panchayath. The geographical coordinates of Bhopatpura Village lies between latitude 25.314676° North and longitude 75.735832° east. In this village *Rosa rubiginosa* and *Tagetes erecta* flowers are cultivated. Other crops are also cultivated in this village like *Triticum aestivum*, *Cicer arietinum* and different types of vegetables (*Spinacia oleracea*, *Raphanus sativus*, *Pisum sativum* and *capsicum frutescense*).

Site 4 is Kolipura Village which is located in Ladpura tehsil of Kota district in Rajasthan, India. It is situated 38 km away from sub-district headquarter Ladpura (tehsildar office) and 38 km away from district headquarter Kota. It is located near the Mukundra Hills Tiger Reserve which is a protected area

that includes the Mukundra Hills National Park, Darrah Sanctuary, Jawahar Sagar Wildlife Sanctuary, and part of the National Gharial Sanctuary. The geographical coordinates of Kolipura Village lies between latitude 25.2021° North and longitude 75.8567° east. This area is endowed with lush green vegetation. Various plant species observed in this area are as follows- Different plant species present in Chatra villas garden are *Leucophyllum frutescens*, *Lantana camara*, *Niphar advena*, *Hamelia patens*, *Phlox*, *Crimin asiaticum*, *Langerstroemia indica*, *Parthenium hysterophorus*, *Murraya paniculata*, *Tridax Procumbens*, *Mangifera indica*, *Nelumbo nucifera*, *Acacia arabica*, *Calotropis procera*, *Hibiscus rosa-sinensis*, *Psidium guajava* *Allamanda cathartica*, *Bougainvillea glabra*, *Calotropis procera*, *Acacia catechu*, *Eicchornia crassipes*, *Ficus benghalensis*, *Parthenium hysterophorus* and *Azadirachta indica* etc.

Methods of sampling and identification of Butterflies

The sampling was done by "Line Transect Method". All the sites were visited at regular intervals. Butterflies were observed between 7 am to 11 am and in evening 4 pm to 6 pm. To identify the butterflies, they were caught using aerial net, photographed and then safely released back into the environment. Insects were photographed using Nikon Z611. The insects were identified based on their wings color, pattern, shapes, sizes, with the help of entomological experts, and available literature.

Statistical analysis: Data of identified species was analyzed for richness and abundance by using various diversity indices.

Shannon-Wiener diversity index (H')

It is alpha diversity index and it depends upon species richness and species evenness. Shannon-Wiener diversity index (Shannon, 1949) was calculated

$$H' = -\sum (p_i * \ln(p_i))$$

Where $p_i = S / N$

S = number of individuals of one species

N = total number of all individuals in the sample

ln = logarithm to base e

2: Simpson's Index (D)

Simpson's index denotes the alpha diversity of the selected area. It depends on both species richness and evenness. The Simpson's Index (Simpson, 1949) was calculated as-

$$D = \sum (n_i - 1) / N (N - 1)$$

Where

N = total number of individuals

n_i = number of individuals of i th species

Simpson Index of Diversity (1 - D)

The Simpson Index of Diversity (1 - D) is a measure of diversity that takes into account both richness (the number of species) and evenness (the relative abundance of species). It reflects the probability that two individuals randomly selected from a sample will belong to different species.

$$1 - D = 1 - \sum (n_i - 1) / N (N - 1)$$

• n_i = number of individuals of species i

• N = total number of individuals of all species

- D = Simpson's Index (dominance index; probability two individuals are the same species)
- 1-D = Simpson's Diversity Index (probability two individuals are different species)

4 Margalef's Index (D_{Mg})

This index is also an alpha diversity index and used as a simple measure of species richness (Magurran, 1988).

$$D_{Mg} = (S - 1) / \ln N$$

S = total number of species

N = total number of individuals in the sample

ln = natural logarithm

5 Pielou's Evenness Index (J')

Pielou's index is an alpha diversity index that measures how evenly species are distributed in a community (Pielou, 1969).

$$J' = H' / \ln(S)$$

H' = Shannon - Wiener diversity index

S = total number of species in the sample

6 Relative abundance of butterfly families

The relative dominance of butterfly families was calculated by using dominance index.

$$\text{Relative abundance (family wise)} = n_i \times 100 / N$$

Where n_i = number of butterflies in the 'i' th family, and

N = the total number of butterflies in all the families collected in each habitat

7. Jaccard's Index (J)

The Jaccard Similarity Index measures the proportion of shared species between two communities relative to the total number of species found in both.

$$J = S_c / S_a + S_b + S_c$$

Where S_a and S_b are the number of species unique to Site a and Site b respectively, and S_c is the number of species common to both the sites.

Results and Discussion

Butterfly species distribution among families and species composition: In the year 2022-2023, total of 1,612 individuals and in the year 2023-2024 total of 1,692 individuals of 38 species belonging to 5 families of superfamily Papilionoidea were recorded. In both the years similar number of species were reported at site 4 (Kolipura- 38 species), site 2 (Abhedha- 11 species) and site 3 (Bhopatpura- 8 species). Whereas at site 1 (C.V garden) 19 species were reported in the year 2022-2023 and 25 species were reported in the year 2023-2024.

In terms of species the least dominant family in both the years is Hesperidae at site 1 and site 4. At site 2 (Abhedha) the least dominant family in terms of species was Lycaenidae (18.18%) followed by Pieridae (27.27%) in both the years. While at site 3 in both the years, Lycaenidae (25%) and Pieridae (25%) showed the similar percentage in terms of species composition.

The most dominant family in terms of species composition at all the four sites in both the years was Nymphalidae family.

Table 1: Family wise percentage composition of species in the year 2022-2023

S. No.	Families	C.V garden	Abhedha	Bhopatpura	Kolipura
1	Papilionidae	15.78%	-	-	10.52%
2	Pieridae	21%	27.27%	25%	23.68%
3	Lycaenidae	21%	18.18%	25%	18.42%
4	Nymphalidae	36.8%	54.54%	50%	47.36%
5	Hesperidae	5.26%	-	-	5.26%

Table 2: Family wise percentage composition of species in the year 2023-2024

S.No.	Families	C.V garden	Abhedha	Bhopatpura	Kolipura
1	Papilionidae	16%	-	-	10.52%
2	Pieridae	16%	27.27%	25%	23.68%
3	Lycaenidae	24%	18.18%	25%	18.42%
4	Nymphalidae	40%	54.54%	50%	47.36%
5	Hesperidae	4%	-	-	5.26%

Table 3: Comparison between site 1, 2, 3 and 4 with respect to families, species and individuals in the year 2022-2023, 2023-2024

Sites	Number of Families		Number of species		Number of individuals	
	2022-2023	2023-2024	2022-2023	2023-2024	2022-2023	2023-2024
1	5	5	19	25	205	365
2	3	3	11	11	191	86
3	3	3	8	8	30	37
4	5	5	38	38	1186	1204

At site 1 in the first years the most abundant species reported were *Eurema laeta* and *Danaus chrysippus*. While in the year 2023-2024, *Eurema hecabe* was the most abundant species. At site 2 was *Pseudoizeeria maha* (50) was the most abundant species reported in the year 2022-23, whereas in the year 2023-24 at site 2, *Danaus genutia* (20) was the most abundant species reported. Due to indiscriminate cutting of plants at site 2, plant composition in the area changed it lead to the decline of host plants preferred by *Pseudoizeeria maha*

and favored those plants used by *Danaus genutia*. At site 3, *Danaus genutia* was the most abundant species reported in both the years. At site 4, *Danaus chrysippus* (64) and *Eurema hecabe* (66) was the most abundant species in the year 2022-23 and 2023-24 respectively, so due to change in plant composition the dominant species shifted. It highlights the dynamic nature of butterfly populations and their sensitivity to environmental changes.

Species diversity, richness and abundance

Alpha diversity: Alpha diversity refers to the number and variety of species (or other taxonomic units) in a specific, relatively small, and uniform habitat.

In both the years the highest Relative abundance was showed by the Nymphalidae family followed by family Pieridae, Lycaenidae, Papilionidae and Hesperidae. The abundance of

Nymphalidae can be due to polyphagous habit that helped them to live in all habitats (Sreekumar and Balakrishnan, 2001b)^[43]. The higher number of Pieridae and Lycaenidae is supported by studies of Bernard who reported that that these two families can be seen almost everywhere. But at the site 2 in the year 2022-2023 the second highest Relative dominance was showed by the Lycaenidae family followed by Pieridae (Table 5a).

Table 5a: Relative abundance of various families at four different sites in the year 2022-2023

S.No.	Families	C.V garden	Abheda	Bhopatpura	Kolipura
1	Papilionidae	3.41%	-	-	4.72%
2	Pieridae	37%	25.65%	30%	32.20%
3	Lycaenidae	8.29%	27.74%	20%	15.59%
4	Nymphalidae	50.73%	46.59%	50%	46.62%
5	Hesperidae	0.48%	-	-	0.84%

Table 5b: Relative abundance of various families at four different sites in the year 2023-2024

S.No.	Families	C.V garden	Abheda	Bhopatpura	Kolipura
1	Papilionidae	3.56%	-	-	3.23%
2	Pieridae	32.05%	31.39%	29.72%	34.05%
3	Lycaenidae	17.26%	22.09%	18.91%	17.77%
4	Nymphalidae	46.57%	46.51%	51.35%	43.10%
5	Hesperidae	0.54%	-	-	1.82%

Family Papilionidae and Hesperidae were altogether absent at site 2 (Abheda) and site 3 (Bhopatpura village) in both the years. This result favors the statement of Ombugadu *et al.*, (2021)^[24]. The reason for the lowest species richness and abundance showed by Hesperidae family may be their flight period (early morning hours at dawn and dusk, Kehimkar, 2008)^[19] and narrow host plant range and absence of suitable habitat.

Margalef's index is a measure of species richness, considering the number of species and total individuals of a community.

Margalef's index of site 1 (3.381) indicates the moderate species richness which can be improved further with conservation practices. At site 2 and site 3 low Margalef's index (Table-6) indicates a more limited community which have slightly low diversity. Low diversity at these two sites is due to the habitat disturbances and habitat loss. Highest Margalef's index of site 4 reflects the highest species richness and suggests that the ecosystem is much diverse as compared to all the other sites of present study. So the site 4 is ecologically stable and well balanced habitat making it a key conservation area of all the study sites.

During the study period increase in Margalef's index (Table-6) at site 1 indicates a notable improvement in the species richness, this is due to the habitat restoration and improved condition in the habitat. In the two successive years increase in Margalef's index at site 2 shows that there is slight recovery in species richness, though it is relatively low.

At site 2 increase in Margalef's index value is due to decrease in the total number of individuals in the community so it indicates the health of the ecosystem is declining. This is due to indiscriminate cutting of plants from the ecosystem hence disturbing the ecological balance of the ecosystem.

At site 3 there is no remarkable change in the Margalef's index, so there is no notable change in the species richness at site 3.

At site 4 species richness is still the highest and stable, which is indicated by minimal change in the Margalef's index value of site 4 in the two successive years. So making the habitat an ecological hotspot for biodiversity. Positive trend at site 1

suggests that there is improvement in species richness indicating ecological recovery in the habitat.

In the present study highest Shannon-Weiner index and Simpson index of diversity at site 4 indicates a well-balanced ecosystem with high number of species and even distribution of species in both the years. The findings of this study further supported by Hill *et al.*; Brown, Bonebrake *et al.* and Akwashiki *et al.*^[7] who reported great abundance of butterfly species in less disturbed habitats. In the Undisturbed site the higher diversity and abundance was observed, which may be due to the availability of nectar and host plants of butterflies. This result favors the statement of Sreekumar and Balakrishnan (2001a)^[42] they suggest that prevalence of butterfly species at a particular habitat depends on a wide range of factors, of which the availability of the food is the most important.

Second highest Shannon-Weiner index was observed at site 1 (2.288 and 2.924) in both the years, indicating moderate diversity and reasonably diverse community having rich species distribution.

Relatively low Shannon-Weiner index and Simpson index of diversity was reported at site 2 and site 3 which indicates low diversity with fewer species being dominant. In the present study high Shannon-Weiner index of site 4 and site 1 indicates that these two sites are having stable and healthy ecosystem with good resource availability. Lower Shannon-Weiner index and Simpson index of diversity of site 2 and site 3 in the present investigation indicates the environmental disturbances.

In the two successive years there is increase in Shannon-Weiner and Simpson index of diversity at site 1 which indicates the higher species diversity compared to last year, which indicates improved habitat conditions, better resource availability for the butterflies at site 1.

At site 2 and site 3 there is slight increase in Shannon-Weiner index and Simpson index of diversity (Table-6) suggests that there is minor improvement in species diversity but still relatively low as compared to site 1 and site 4. During the study over the last two years there is slight drop in Shannon-

Weiner index and Simpson index of diversity at site 4 which suggests that high diversity is still maintained at site 4 but experiencing small changes in species distribution. Other possible cause for these minor changes is the increasing anthropogenic activity in the study area. So the monitoring of this natural area should be done to ensure the ecosystem stability.

Pielou's index: During the present investigation at site 4 had the highest evenness (Table-6), which indicates that the species are distributed more equally. Therefore no single species is dominating in the ecosystem. Thus ecosystem at

site 4 is stable and healthy ecosystem with minimal competition issues. Similarly site 3 also has high evenness indicating good species balance in the ecosystem though slightly lower than site 4. However site 1 and site 2 have moderate evenness with some species being more dominant at these sites. This in turn reduces the evenness of the ecosystem. Such results are due to the habitat disturbances like indiscriminate cutting of plants in the ecosystem. Lower evenness in the ecosystem contributes to the lower biodiversity as dominant species outcompete the other species.

Table 6: Comparison of butterfly diversity indices in site 1, site 2, site 3 and site 4

Sites	Shannon-Weiner Index (H')		Simpson index of diversity (1-D)		Pielou's Index (J')		Margalef's Index (D _{Mg})	
	2022-2023	2023-2024	2022-2023	2023-2024	2022-2023	2023-2024	2022-2023	2023-2024
1	2.288	2.924	0.865	0.938	0.777	0.908	3.381	4.068
2	1.883	2.056	0.824	0.858	0.785	0.857	1.904	2.245
3	1.905	1.938	0.863	0.862	0.916	0.932	2.058	1.939
4	3.506	3.458	0.968	0.966	0.963	0.950	5.227	5.216

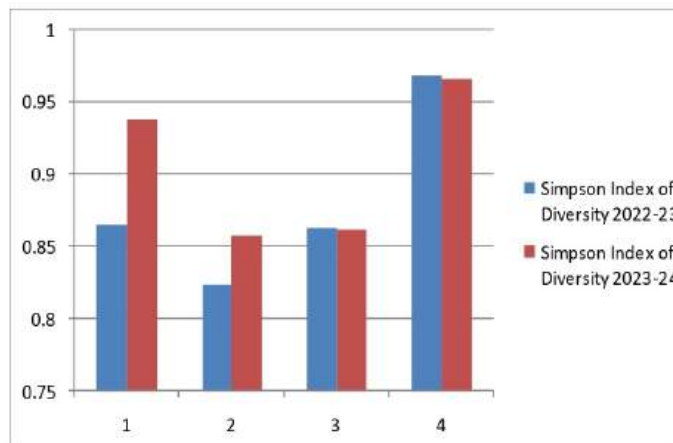
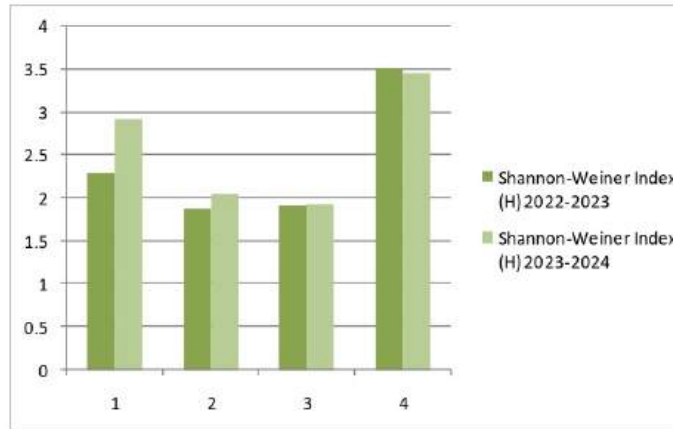


Fig 1a & 1b: Comparison of Simpson's index of diversity and Shannon-Weiner index of site 1, site 2, site 3 and site 4.

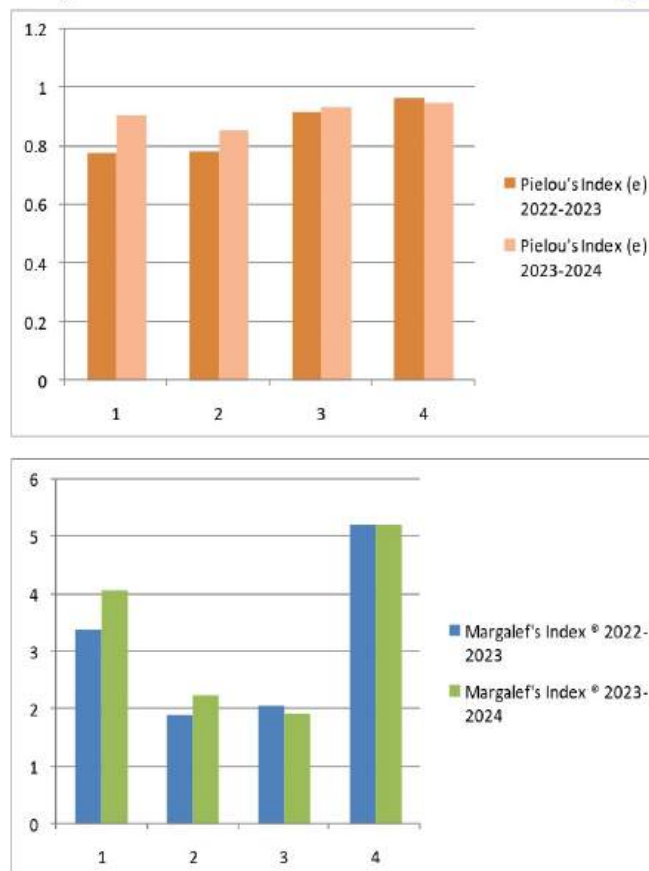


Fig 2a & 2b: Comparison of Pielou's index (species evenness) and Margalef's index (species richness) of site 1, site 2, site 3 and site 4

2. Beta diversity

It is a measure of changes in species composition between different ecosystems. It reflects how the biodiversity varies across the spatial scales.

Beta diversity in the year 2022-2023, site 2 and site 3 show relatively high similarity as indicated by the Jaccard index value of site 2 and site 3 (0.30) suggesting that 30% of the species are common between these two sites. The Jaccard index value (0.27) of site 1 and site 2 indicates moderate similarity with nearly half of the species shared between the two sites. Similarly Jaccard index value of site 1 and site 4 (0.25) also indicates moderate similarity showing that 25% of the species are shared between these two sites.

Jaccard index value (0.23) of site 1 and site 3 shows a lower similarity with approximately 23% of species in common. Low Jaccard index value of S2-S4 and S3-S4 suggests minimal overlap in species composition between these two pairs of sites. Overall site 2 and site 3 share the most species, while site 3 and site 4 have least in common so beta diversity is highest in S3-S4 as these two sites show significant difference in species composition.

Beta diversity is lowest at S2-S3 sites, as these two sites share

similar species indicating the homogeneity in the ecosystem.

Beta diversity in the 2023-2024 at S2-S3 sites show high similarity, which is indicated by the highest Jaccard's index value (0.30). As 30% of the species are common in between these two sites. In the year 2023-2024 Jaccard's index value of S1-S4 reached 0.28, indicating the high similarity with 28% of the species shared between these two sites. S1-S2 sites showed lower similarity with comparatively low Jaccard index value (0.23), with approximately 23% of the species in common.

S1-S3 sites overlap with 19% of species shared between these two sites, which is indicated by their Jaccard index value (0.19). Lowest value of Jaccard index of S2-S4 (0.18) and S3-S4 (0.15) indicates that there is very little overlap in species composition between these two pairs of sites. Overall, we can say that S2-S3 site share the most species while S3-S4 have the least common species in both the years.

Beta diversity is highest at S3-S4 as these two sites show significant difference in species composition in both the years. Beta diversity is lowest at S2-S3 sites as these two sites share similar species in both the years indicating the homogeneity in the ecosystem.

Table 7: Jaccard's Index of Butterflies (2022-23, 2023-2024)

Sites	2022-2023	2023-2024
S1-S2	0.27	0.23
S1-S3	0.23	0.19
S1-S4	0.25	0.28
S2-S3	0.30	0.30
S2-S4	0.18	0.18
S3-S4	0.15	0.15

3. Gamma Diversity: It describes the overall species diversity across communities within a large geographical area.

Table 8: Gamma Diversity in the year 2022-2023 at site 1, 2, 3 & 4

Sites	Number of families of butterflies	Number of species of butterflies	Number of individuals of butterflies
1	5	19	205
2	3	11	191
3	3	8	30
4	5	38	1186
Gamma diversity	5	38	1,612

Table 9: Gamma Diversity in the year 2023-2024 at site 1, 2, 3 & 4

Sites	Number of families of butterflies	Number of species of butterflies	Number of individuals of butterflies
1	5	25	365
2	3	11	86
3	3	8	37
4	5	38	1204
Gamma diversity	5	38	1,692

Conclusion

Based on the work carried out during this study, we can conclude that the diversity of butterfly species was found to be higher in natural sites due to minimal human interference. This indicates that the conservation of natural and less-disturbed areas is essential for preserving biodiversity.

The study also found that the number of butterflies was relatively low in agriculture lands. The main reason for this is the excessive and indiscriminate use of pesticides and chemical substances by farmers, often without proper knowledge. These chemicals are not only harmful to pests but also to beneficial pollinators like butterflies. Since butterflies play an important role in crop pollination, their declining numbers are a matter of concern for the agricultural system as well. There is a need for farmers training to promote integrated pest & pollinator management (IPPM) strategies to reduce over reliance on chemical pesticides in the management of crop pests (Meissle *et al.*, 2010). The second possible reason for the decline in butterfly numbers may also attributed to the practice of monoculture farming, which reduces habitat heterogeneity and limits the availability of diverse nectar and host plants.

During the study, we also observed that at Abhedra site, in the following year, there was a noticeable decline in butterfly diversity due to excessive and insensitive cutting of plants. This indicates that if we continue to exploit natural resources indiscriminately, it will not only disturb the ecological balance but also endanger the existence of those species that are integral to the ecosystem. Protecting nature is not just about conserving the environment, but also about safeguarding all the living beings that depend on it.

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