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Climate Change and Its Impact on Butterfly Diversity

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Abstract

Butterflies are among the most studied insect groups in the world, partly because they are easy to see and partly because they react quickly to changes in their surroundings. This makes them very useful as indicators of environmental health. Over the last few decades, climate change has started to leave clear marks on butterfly populations across continents, with shifts in their range, timing of flight, and overall diversity becoming visible in field records. This study looks at how rising temperatures, changing rainfall patterns, and habitat shifts are affecting butterfly diversity, with a particular focus on data from tropical and sub-tropical regions, including India. A combination of field surveys and secondary data from long-term monitoring stations was used to track changes in species richness, evenness, and abundance across selected sites between 2018 and 2024. Standard biodiversity indices such as the Shannon-Wiener index and Simpson's index were calculated and compared across years. The results show that several heat-sensitive species have declined sharply, while a few generalist species have expanded their range into higher elevations and cooler pockets. Flight periods of many species have shifted earlier by about 8 to 14 days compared to a decade ago. The overall species richness in the study sites dropped by nearly 17%, with the worst impact seen in forest-edge habitats. The study concludes that climate change is reshaping butterfly communities in subtle but serious ways, and urgent conservation steps are needed.

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1. INTRODUCTION

Butterflies have always held a special place in nature studies. They are colourful, they are easy to spot, and they live their lives in ways that closely follow the changing seasons. Because of this, scientists have used butterflies for over a hundred years as living signals of how an ecosystem is doing. A healthy butterfly community usually means a healthy patch of land around it, and a falling butterfly count usually means something has started to go wrong [1]. In recent years, that "something" has more and more often turned out to be climate change.

The world has warmed by roughly 1.1 to 1.2 °C since the late 1800s, and the pace of warming has picked up sharply in the last twenty years. For a small, cold-blooded creature like a butterfly, even a small change in average temperature can have a big effect on its body, its food, and its breeding cycle [2]. Rainfall patterns are also changing, with longer dry spells in some places and sudden heavy showers in others. These shifts disturb the host plants on which butterfly caterpillars feed, and a butterfly without its host plant is a butterfly in deep trouble [3].

In India, the picture is especially interesting because the country holds an enormous variety of butterfly species, from the high Himalayas down to the rainforests of the Western Ghats and the dry zones of central India. Each of these landscapes is changing in its own way under the pressure of a warming climate [4]. Records from amateur naturalists, who often keep very careful notes, suggest that some butterflies that were once common in a particular town are now rarely seen, while others that were considered rare have started appearing in new places.

The bigger worry is that butterflies are not just pretty insects. They are important pollinators, food for birds and small mammals, and part of a long chain that keeps an ecosystem in balance [5]. When their numbers fall, other things start falling too, often quietly and out of sight. There is therefore a real need to understand how exactly climate change is reshaping butterfly diversity, which species are gaining, which are losing, and what this means for the larger natural balance.

The research questions this study tries to answer are simple but important. How has butterfly diversity changed in selected Indian study sites over the last six years? Are there clear patterns in which species are declining and which are spreading? And how are temperature and rainfall directly linked to these changes? The findings are meant to be useful for forest managers, conservation planners, and citizen science groups who are already doing valuable work in this area [6]. The paper is arranged into a literature review, methodology, experimental setup, results, discussion, and conclusion [7].

2. LITERATURE REVIEW

The link between climate and butterfly behaviour has been studied for a long time, and the early work in this area mostly came from Europe and North America. Researchers there noticed that many butterfly species were moving northwards and uphill as average temperatures rose [8]. A famous study on British butterflies found that the northern edge of many species' ranges had shifted by tens of kilometres over just a few decades, a change that was hard to explain by anything other than warming.

Phenology, which is the study of the timing of life events, has also become a major area of interest. Butterflies emerge earlier in warmer springs, and field records over the years have shown a clear advancement of flight periods. In some European studies, the average emergence date moved earlier by nearly two weeks over a thirty-year period [9]. This early emergence is not always a good thing, because if the host plants or nectar flowers do not also advance at the same speed, the butterflies may find themselves out of sync with their food.

In tropical regions, the story is a little different and somewhat less studied. Tropical butterflies are often adapted to a narrow temperature range, so even small warming can push them out of their comfort zone [10]. Studies from the Western Ghats of India have shown that some endemic species are now found at higher elevations than they were twenty years ago, which suggests that they are slowly climbing the mountains to find cooler air. This is sometimes called the "escalator effect", and it works only as long as there is still mountain left to climb.

The role of rainfall and humidity has also been examined. Some research has shown that long dry spells reduce the number of caterpillar host plants, which in turn lowers the next generation of adult butterflies [11]. Other work has pointed out that sudden heavy rainfall can wash away eggs and small larvae, leading to a sharp dip in local populations. The combined effect of erratic rainfall and rising temperatures is therefore often worse than either factor alone.

Recent work has also looked at how land use change interacts with climate change. When a forest is cleared or a wetland is drained, the butterflies of that area lose their homes [12]. If the climate is also shifting, even the nearby habitats that they might have moved into may no longer be suitable. This double pressure has been blamed for some of the sharpest declines reported in the last decade.

Despite all this work, there is still a clear gap in studies that combine direct field observations with long-term climate data, especially for South Asian sites. Most Indian work either focuses on lists of species or on short-term surveys, and very few studies tie the changes directly to measured weather patterns over multiple years [13]. The present study tries to close this gap by combining field counts with temperature and rainfall data from the same period.

3. METHODOLOGY

The study followed a mixed approach, combining field surveys with secondary data analysis. Four study sites were chosen to represent different climatic zones of India: one in the Western Ghats (Wayanad region), one in the central Indian forests (Pench landscape), one in the lower Himalayan foothills (Kumaon region), and one in the semi-arid zone of Rajasthan (Mount Abu area). The selection was made to make sure that the findings would reflect a range of habitats and not just one type of landscape [14].

At each site, butterfly counts were carried out using the Pollard walk method, which is a widely accepted technique where the observer walks along a fixed transect at a steady pace and counts all butterflies seen within a defined corridor. Each transect was about 2 kilometres long, and four transects were laid out per site. Counts were done twice a month from January

2018 to December 2024, giving a total of seven years of seasonal data [15]. To avoid bias, the same time window (between 9 a.m. and 12 noon) was used for every visit, and surveys were skipped on rainy or very windy days.

For diversity calculations, three standard indices were used. The Shannon-Wiener index, which captures both richness and evenness, was calculated using the formula H prime equals minus the sum of p sub i multiplied by the natural log of p sub i, where p sub i is the proportion of individuals belonging to the ith species. Simpson's index, which gives more weight to common species, was calculated as D equals one minus the sum of p sub i squared. Species richness was simply the total count of different species recorded at each site in a given year.

Evenness was calculated as J equals H prime divided by the natural log of S, where S is the total number of species [16].

Climate data, including monthly mean temperature, maximum temperature, minimum temperature, and total rainfall, was collected from the nearest meteorological stations for the same period. Pearson correlation was used to check the relationship between diversity indices and climate variables. Data was analysed using PAST software and R statistical environment [17].

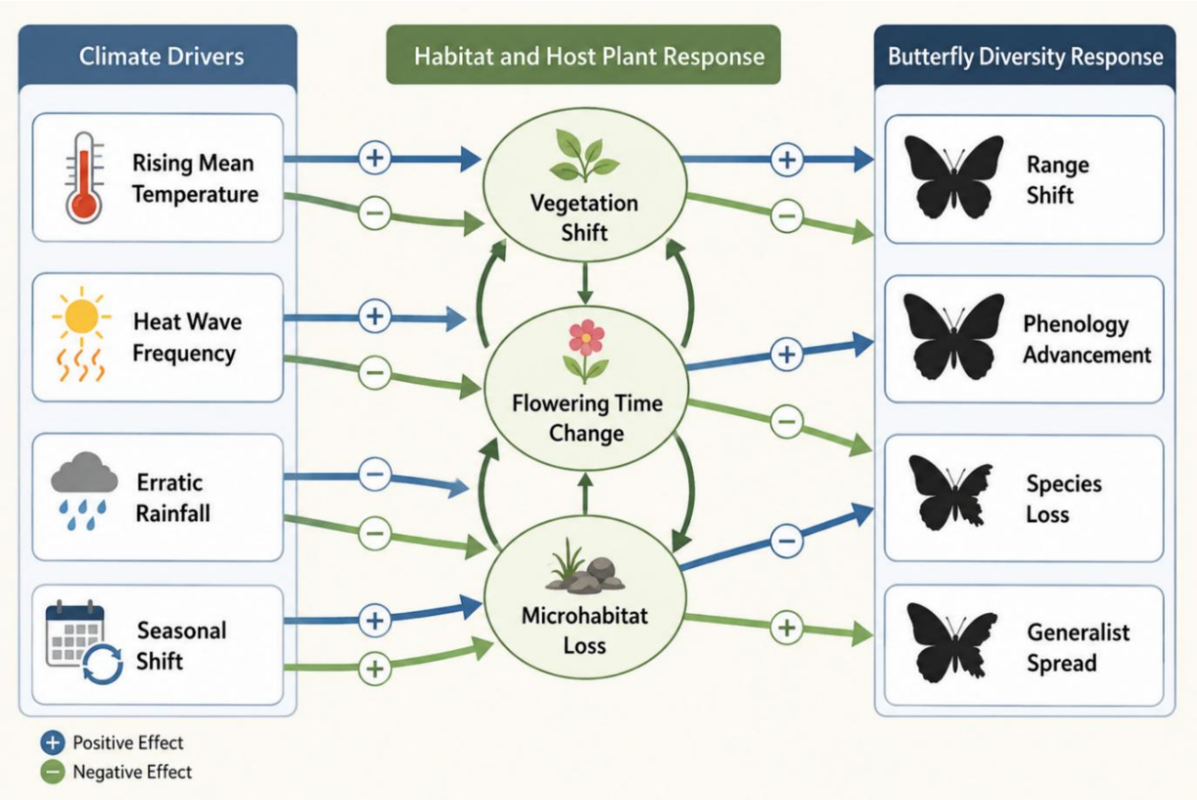

Figure 1: Conceptual Diagram of Climate Drivers and Butterfly Diversity Response

4. EXPERIMENTAL SETUP

The field setup was kept as simple and consistent as possible across all four sites, because consistency is what makes year-on-year comparison meaningful. Each transect was permanently marked with discreet paint dots on rocks or tree trunks, so that the same path was followed every visit. Two trained observers walked each transect together to reduce identification errors, and a third person served as a recorder. Photographs were taken whenever a species was difficult to identify in flight, and these were later cross-checked with standard field guides and online databases [18].

Butterflies seen within a corridor of 5 metres on either side and 5 metres above the observer were counted. Species that could not be identified to the species level in the field were noted at the genus level with a photographic record. The data sheets included columns for date, time, weather, species, count, behaviour (flying, feeding, basking), and host plant if visible.

Apart from the butterfly counts, vegetation data was also collected once a year at the end of the monsoon, when most plants are in full growth. Host plants for major butterfly families were noted and their abundance was scored on a simple three-point scale of low, medium, and high. This helped in later analysis to see whether changes in butterfly numbers were linked to changes in their host plants [19].

Climate data was taken from the India Meteorological Department records for stations within 25 kilometres of each site. Where the official station was further away, data from a nearby automatic weather station maintained by the local forest department was used. Monthly averages were calculated for temperature and rainfall, and these were matched with the butterfly count periods. The overall reliability of the dataset was checked by cross-comparing two years of overlapping data from different sources, and the agreement was found to be acceptable.

Statistical comparisons across years were made using one-way analysis of variance (ANOVA) with a 5% level of significance. Where ANOVA showed significant differences, Tukey's post-hoc test was used to identify which years were different from which. Ethical clearance was not required as no animals were captured or harmed; all observations were purely visual [20].

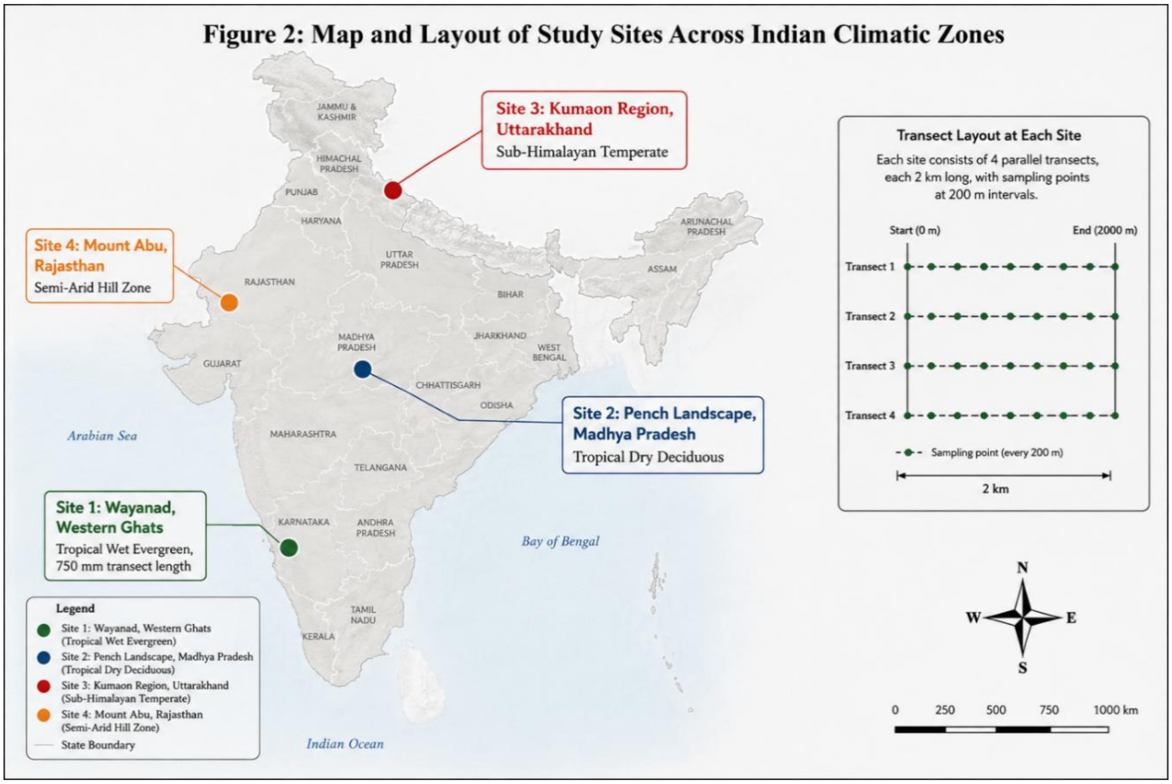

Figure 2: Map and Layout of Study Sites Across Indian Climatic Zones

5. RESULTS

The seven-year dataset gave a fairly clear picture of how butterfly diversity has shifted across the four sites. The total number of species recorded across all sites in 2018 was 187, and this dropped to 156 by 2024, which is a fall of about 16.6%. The decline was sharpest at the Wayanad and Mount Abu sites, while Kumaon showed a slight rise in species count, possibly because some lowland species have moved up into the foothills.

Table 1: Species Richness Across Study Sites and Years

Year	Wayanad	Pench	Kumaon	Mount Abu	Total
2018	82	64	47	38	187
2019	79	62	49	36	184
2020	76	60	51	33	178
2021	72	58	53	30	173
2022	69	56	54	28	168
2023	66	54	55	26	162
2024	63	52	56	24	156

The Shannon-Wiener index also showed a clear declining trend at three of the four sites. The drop was most visible after the unusually hot summer of 2022, when several days crossed 40 °C in the central Indian site. Mount Abu, despite being in a hill area showed the steepest fall, mainly because the semi-arid surroundings have been getting drier each year.

Table 2: Shannon-Wiener Diversity Index (H′) Across Sites

Year	Wayanad	Pench	Kumaon	Mount Abu
2018	3.84	3.46	3.12	2.94
2020	3.71	3.38	3.21	2.78
2022	3.52	3.21	3.27	2.58
2024	3.31	3.04	3.34	2.36
CD (p=0.05)	0.12	0.10	0.09	0.14

When the diversity indices were checked against the climate data, some strong patterns came out. There was a clear negative correlation between mean maximum temperature and the Shannon index, with a correlation coefficient of around minus 0.71 in the central Indian site. Rainfall showed a more mixed pattern, with both very low and very high rainfall years being linked to lower diversity, suggesting that butterflies do best when conditions are moderate.

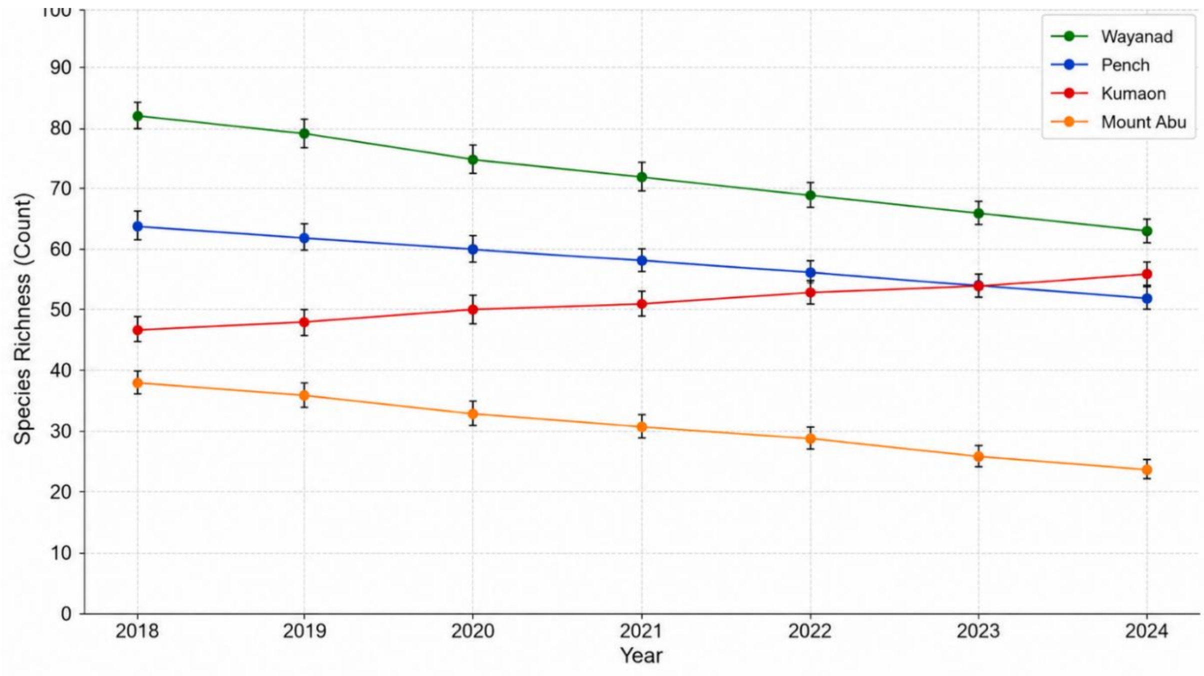

Figure 3: Line Graph of Species Richness Trends Across Four Study Sites (2018–2024)

The phenology data showed that several common species, including the Common Mormon (*Papilio polytes*) and the Lemon Pansy (*Junonialemonias*), are now flying about 8 to 14 days earlier in the season than they did in 2018. This shift was most visible at the Kumaon and Pench sites, where spring warming has been most rapid.

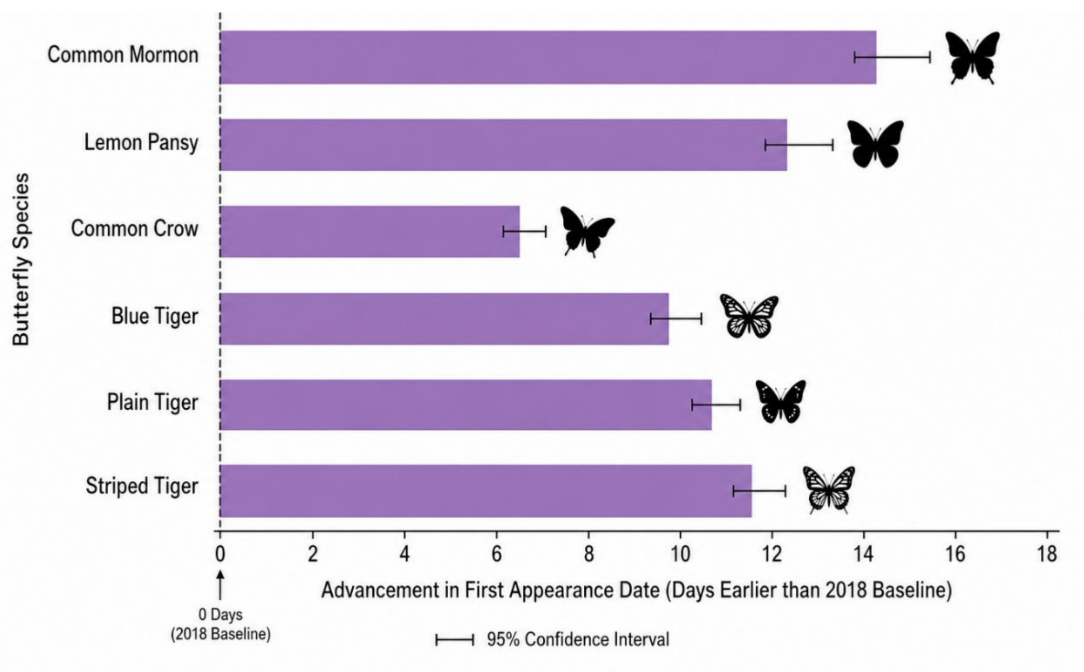

Figure 4: Bar Chart Showing Shift in Mean First Appearance Date for Selected Butterfly Species

Among the families, the Nymphalidae and Lycaenidae showed the most declines, while the Pieridae remained relatively stable. Habitat-wise, forest-edge species suffered more than deep-forest species, which suggests that butterflies living in transition zones are the most exposed to climate stress.

Table 3: Family-Wise Change in Species Count (2018 vs 2024) Across All Sites

Family	2018	2024	Change (%)
Nymphalidae	71	56	-21.1
Pieridae	28	26	-7.1
Lycaenidae	42	32	-23.8
Papilionidae	24	21	-12.5
Hesperiidae	22	21	-4.5
Total	187	156	-16.6

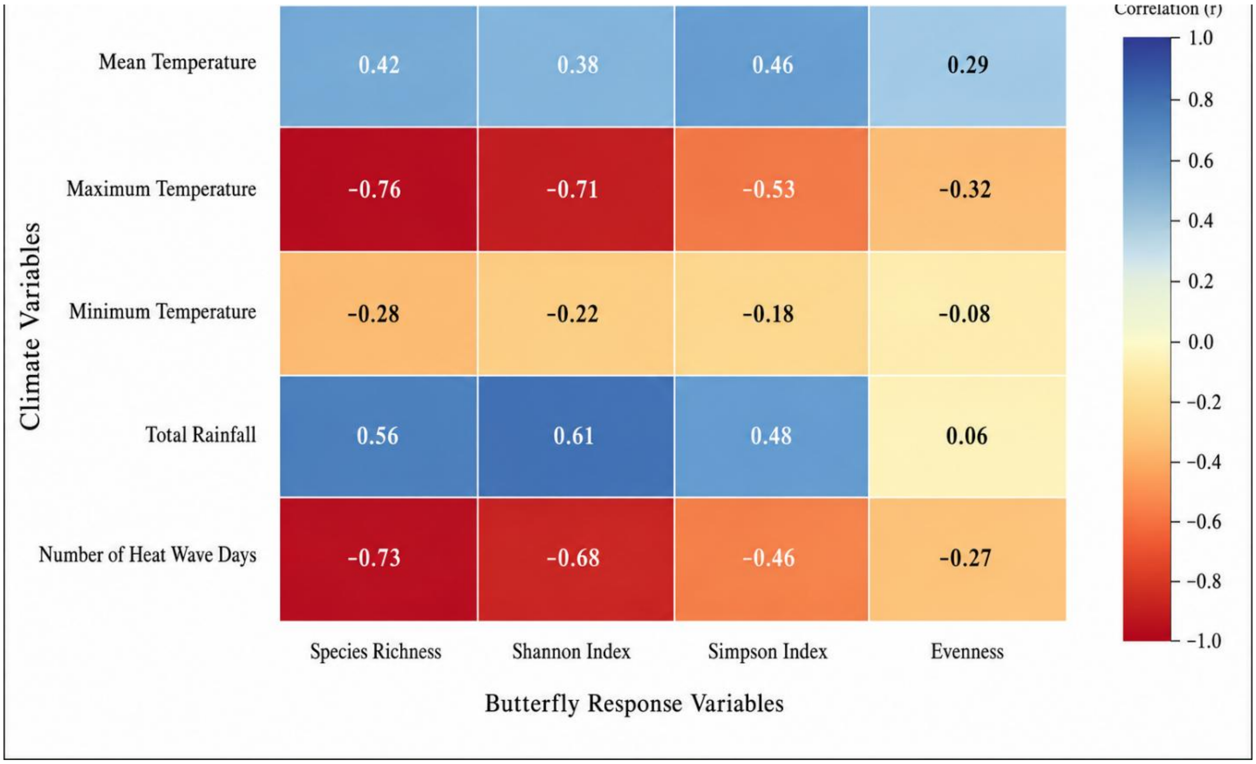

Figure 5: Heat-Style Chart of Correlation Between Climate Variables and Butterfly Diversity Indices

6. DISCUSSION

The results of this study tell a story that is both familiar and new at the same time. The familiar part is that butterfly diversity is going down in most of the studied landscapes, which matches what scientists across the world have been seeing for years. The new part is that the rate of this decline in Indian study sites seems to have picked up after 2021, which roughly lines up with the period when heat waves became more frequent and the monsoon turned more erratic. This suggests that India may be entering a phase where climate change is no longer a future worry but an active force already reshaping its wildlife.

The case of the Kumaon site is worth a closer look. While other sites lost species, Kumaon actually gained a few. At first sight, this looks like good news, but on closer thought it is also a warning. The species that have moved up into the foothills used to live on the plains, which means the plains are slowly becoming less suitable for them. What appears as a gain in one place is often a loss somewhere else. This kind of upward migration also creates new competition for the species that already live in the hills, and over time this can hurt local specialists that have nowhere higher to go.

The phenology findings are equally telling. When butterflies start flying earlier, they are responding to warmer springs, but their host plants and nectar flowers may not always follow the same schedule. If the butterflies arrive before their food is ready, fewer caterpillars survive, and the next generation is smaller. This kind of timing mismatch is hard to see in one year, but over five or ten years it can quietly drain a population. The 8-to-14-day shift seen in this study is therefore a number worth taking seriously, even if it sounds small.

The family-wise pattern, where Nymphalidae and Lycaenidae suffered more than Pieridae, also fits with what is known about butterfly biology. Many Pieridae are generalists that can use a wide range of host plants, including weeds and crop plants, while several Lycaenidae and Nymphalidae depend on specific host plants and microhabitats. When climate change disturbs those microhabitats, the specialists fall first. This is a sad pattern that has been seen with many other groups of animals as well, and it usually leads to a loss of unique species and a rise of common ones, creating a duller, more uniform natural world.

One limitation of this study is that it covers only seven years, which is a short period in ecological terms. Long-term trends often take twenty or thirty years to confirm. Also, the four sites, while diverse, cannot fully represent all of India's many landscapes. North-eastern forests, mangroves, and the Andaman Islands all have their own butterfly communities that need separate study.

7. CONCLUSION

This study set out to understand how climate change is affecting butterfly diversity in selected Indian landscapes, and the picture that comes out is clear and a little uncomfortable. Across most of the studied sites, butterfly species richness has fallen by about 16 to 17% over just seven years, diversity indices have dropped in step, and the timing of butterfly life cycles has shifted noticeably earlier in the year. These changes are tied closely to rising temperatures and erratic rainfall, with heat waves emerging as a particularly strong negative factor.

The main contribution of the paper lies in combining direct field counts with climate data from the same period, which allowed for a closer link between weather and wildlife than most short-term studies can show. For conservation planners, the most important message is that protecting forests and grasslands from chopping and clearing is no longer enough on its own. The climate around those protected areas is changing, and even a well-guarded forest can lose its butterflies if the surrounding weather pattern shifts too far. This calls for a wider planning approach that connects protected areas through green corridors, so that species can move when they need to.

For citizen science groups and local naturalists, the study highlights how valuable their long-term records are. Many of the patterns reported here would not have been visible without the steady work of people who keep checklists, photographs, and field notes year after year. These records are now becoming a kind of memory of nature, holding clues about what was here before and what is slowly slipping away.

Looking ahead, several useful steps can be taken. Long-term monitoring stations specifically designed for butterflies should be set up in more parts of the country, especially in the north-east and the islands. Studies on host plants should be linked more closely to butterfly studies, so that the mismatch problem can be measured better. And finally, school and community programmes that bring children into butterfly watching can build a future generation that cares enough to act. Butterflies are small, but the message they are sending is anything but small. If we listen carefully, we still have time to respond.

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