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Impact of climate change on butterfly diversity in Sikar, Rajasthan

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Abstract
Climate change poses significant threats to biodiversity, particularly affecting sensitive indicator species such as butterflies. The semi-arid region of Sikar, Rajasthan, has experienced notable climatic shifts over recent decades, potentially impacting local butterfly populations. This study investigates the impact of climate change on butterfly diversity in Sikar district, examining species composition, abundance patterns, and distributional shifts in relation to changing climatic variables. Butterfly surveys were conducted across four distinct seasons from January 2022 to December 2023 at twelve selected sites representing varied habitats. Standard transect methods were employed, with simultaneous recording of microclimate data. Historical climate data (1990-2023) were analyzed to identify long-term trends. Species diversity was assessed using Shannon-Wiener and Simpson indices, while climate-diversity relationships were examined through canonical correspondence analysis. A total of 87 butterfly species belonging to 6 families were recorded, with Nymphalidae (28 species) being the most diverse. Significant positive correlations were observed between temperature increase and reduced species richness ($r = -0.67$, $p < 0.01$). Summer temperatures have increased by 1.8°C over three decades, while rainfall patterns showed increased variability. Thermophilic species showed range expansion, while mesophilic species exhibited population declines averaging 34%. Five species previously recorded in historical surveys were not encountered during the study period. Climate change is significantly affecting butterfly diversity in Sikar, with evidence of species turnover, phenological shifts, and altered community composition. Conservation strategies must incorporate climate adaptation measures to preserve butterfly diversity in this semi-arid ecosystem.

Keywords: Butterfly diversity, climate change, *Lepidoptera*, semi arid ecosystem, species richness, Sikar district, temperature impact, phenological shift

Introduction

Climate change is one of the most serious environmental challenges of the 21st century, significantly affecting global biodiversity (IPCC, 2021) [9]. Rising temperatures, changing rainfall patterns, and extreme weather events are forcing species to adapt, migrate, or face extinction (Parmesan & Yohe, 2003) [11]. Insects are especially vulnerable due to their ectothermic nature and habitat specificity (Deutsch *et al*., 2008) [5]. Butterflies are widely used as bioindicators because they are highly sensitive to temperature changes and depend on specific host plants Studies show clear shifts in butterfly distribution and timing of life cycles in response to global warming (Roy *et al*., 2001; Wilson *et al*., 2005) [12, 14], including northward range shifts in many European species

Rajasthan, the largest state of India, has diverse ecosystems from desert to semi-arid and sub-humid zones. The state is experiencing rising temperatures (over 0.5°C per decade) and changing monsoon patterns (Kumar *et al*., 2020) [10]. Semi-arid regions like Sikar are highly vulnerable to these changes. Long-term data show increasing temperatures and rainfall variability, with frequent droughts and occasional extreme rainfall events (Srivastava *et al*., 2019; Yadav *et al*., 2021) [15]. These changes strongly affect vegetation and insect populations. Butterfly Diversity in Rajasthan - Rajasthan supports around 150 butterfly species despite its arid climate (Sharma & Joshi, 2009). These species are adapted to dry conditions but still depend on suitable vegetation and water availability. Eastern Rajasthan shows relatively richer diversity in well-vegetated areas (Rathore & Tiwari, 2013). Sikar district is a transitional zone between the Aravalli hills and the Thar Desert, supporting semi-arid vegetation and seasonal biodiversity. However, butterfly data from this region is limited and outdated. Most butterfly research in India focuses on biodiversity-rich regions like the Western Ghats, Himalayas, and Northeast India. Semi-arid regions such as Sikar remain poorly studied (Kehimkar, 2008). This study fills this gap by providing updated baseline data on butterfly diversity in Sikar, analyzing climate trends, and assessing the relationship between climate variables and butterfly communities. It also aims to identify vulnerable species and support conservation planning.

Study Objectives The study aims to:

1. Document butterfly diversity, abundance, and seasonal variation in Sikar district.
2. Analyze long-term climate trends in temperature and rainfall.
3. Study the relationship between climate variables and butterfly diversity.
4. Identify species-level responses such as range or seasonal shifts.
5. Suggest conservation and climate-adaptive management strategies.

Materials and Methods

Study Area Description

Sikar district (27°36'N, 75°08'E) covers an area of approximately 7,742 km² in northeastern Rajasthan, with

elevations ranging from 350 to 550 meters above sea level. The district experiences a semi-arid climate classified as BSh under the Köppen climate classification. Mean annual temperature ranges from 24°C to 26°C, with summer maxima exceeding 45°C and winter minima dropping to 4-6°C. Annual rainfall averages 450-550 mm, concentrated primarily during the southwest monsoon (July-September). The natural vegetation comprises dry deciduous scrublands dominated by *Acacia* spp., *Ziziphus* spp., *Capparis decidua*, and *Prosopis juliflora*. Agricultural areas cultivate pearl millet (*Pennisetum glaucum*), mustard (*Brassica* spp.), and wheat (*Triticum aestivum*) during different seasons. Significant anthropogenic pressure exists due to increasing urbanization, agricultural expansion, and groundwater depletion.

Site Selection and Sampling Design

Twelve sampling sites were strategically selected to represent diverse habitat types within Sikar district, including: (1) natural scrubland (3 sites), (2) agricultural fields and edges (3 sites), (3) urban green spaces (3 sites), and (4) water body peripheries (3 sites). Site selection considered factors such as vegetation heterogeneity, disturbance levels, accessibility, and representation of major land-use categories. Each site consisted of a 500-meter transect established following standard protocols (Pollard, 1977). Transects were positioned to traverse maximum habitat variation while maintaining consistent width (5 meters on either side). GPS coordinates were recorded for each transect, and detailed habitat characterizations were conducted, documenting dominant plant species, canopy cover, soil type, and anthropogenic disturbances.

Butterfly Sampling Methodology

Butterfly surveys were conducted from January 2022 to December 2023 across four seasons: winter (Dec–Feb), summer (Mar–May), monsoon (Jun–Sep), and post-monsoon (Oct–Nov). Each transect was sampled monthly under suitable weather conditions (20–40°C, wind speed <15 km/h, no rain, and adequate sunlight). The Pollard walk transect method was used, where observers walked at a steady pace (~5 m/min) between 0900–1600 h, recording butterflies within a 5 m radius (Pollard & Yates, 1993). Identification was done using standard field guides (Kehimkar, 2008; Kunte, 2000; Varshney & Smetacek, 2015), supported by photographic records. Occasionally, specimens were captured using sweep nets for close examination and released immediately. For each sighting, data on species, abundance, behaviour, host plants, and microhabitat were recorded. Unidentified species were later confirmed using expert consultation and museum references.

Butterfly Diversity

Diversity Indices

Species richness (S) was calculated as the total number of species recorded at each site and season. Alpha diversity was quantified using Shannon-Wiener diversity index (H'):

$H' = -\Sigma (pi \times \ln pi)$

where pi is the proportional abundance of species i. Simpson's diversity index (D) was calculated as:

$D = 1 - \Sigma(pi^2)$

Species evenness was assessed using Pielou's evenness index (J'):

$J' = H' / \ln S$.

Results



Plate 1: Common Mormon, Lime Butterfly, Blue Pansy, Gram Blue

Overall Species Richness

Plate 1 Shows Common Mormon, Lime Butterfly, Blue Pansy, Gram Blue A total of 87 butterfly species belonging to 6 families and 72 genera were recorded from 12 sites in Sikar district during 24 months of surveys. Nymphalidae was the most diverse family (28 species, 32.2%), followed by Lycaenidae (22 species, 25.3%), Pieridae (18 species, 20.7%), Hesperiidae (11 species, 12.6%), Papilionidae (6 species, 6.9%), and Riodinidae (2 species, 2.3%). Species accumulation curves stabilized after about 18 months, indicating adequate sampling effort. The Chao1 estimator predicted 94 ± 4.2 species, suggesting that ~92.5% of the expected fauna was recorded. In total, 3,847 individual butterflies were observed across all surveys.

Threatened and Conservation-Priority Species

Among the 87 species recorded, 12 were identified as requiring conservation attention based on IUCN criteria and observed population trends. *Pachliopta aristolochiae* (Common Rose) was rarely observed (three records) and is threatened by habitat loss and decline of its host plant (*Aristolochia*). *Hypolimnas misippus* (Danaid Eggfly) showed a sharp decline, with only two individuals recorded compared to its earlier common status. Species with specialized ecological requirements were more vulnerable overall. *Colotis amata* (Small Salmon Arab), dependent on *Salvadora* species in scrub habitats, was restricted to only two protected sites, indicating habitat degradation in other areas.

Discussion

Climate Change Impacts on Butterfly Diversity

The present study provides compelling evidence that climate change is significantly affecting butterfly diversity and community composition in Sikar, Rajasthan. The documented 1.8°C temperature increase over three decades, coupled with increased precipitation variability, has created altered environmental conditions that favor certain species while disadvantaging others. The strong negative correlation between temperature and species richness ($r = -0.67$) demonstrates the direct influence of warming on butterfly communities, consistent with predictions from climate-insect interaction theory. These findings align with global patterns of climate-induced butterfly responses documented in temperate regions (Warren *et al*., 2001; Forister *et al*., 2010) [6, 12], but provide critical insights into semi-arid tropical systems that have received less scientific attention. Unlike temperate butterflies that may benefit from moderate warming, species in already-hot regions like Sikar face thermal stress approaching or exceeding physiological tolerance limits (Deutsch *et al*., 2008) [5].

Implications for Semi-Arid Ecosystems

Semi-arid regions like Sikar lie in sensitive transitional zones, making them highly vulnerable to climate change. Even small increases in temperature or reductions in rainfall can shift these ecosystems toward more arid conditions, altering species composition and ecological balance. Increased climate variability, with frequent droughts and extreme rainfall events, further destabilizes habitats. While butterflies can respond quickly to gradual climate change due to their short life cycles, high variability increases stress and extinction risk (Boyce *et al*., 2006) [4]. The decline of moisture-dependent (mesophilic) butterfly species in Sikar reflects broader range contractions seen at species' trailing edges (Thomas *et al*., 2006) [13]. With ongoing warming, the butterfly community of Sikar is likely to become more similar to that of arid western Rajasthan, indicating a shift toward desert-adapted assemblages.

Conclusion

This study highlights clear climate-driven changes in butterfly diversity in Sikar, Rajasthan. Key results show a 1.8°C rise in temperature over three decades, strong negative relationships between temperature and species richness ($r = -0.67$), and climate explaining 34.6% of variation in species composition. A total of 87 species from 6 families were recorded, representing 58% of Rajasthan's butterfly fauna. Warm-adapted species such as *Papilio demoleus* and *Danaus chrysippus* increased, while moisture-dependent species like *Vanessa indica* and *Neptis hylas* declined. Flight periods advanced by about 8.3 days, and moderate species turnover was observed, including local extirpations and new records. Natural scrub habitats supported higher diversity than modified areas, with water-associated microhabitats acting as important refuges. Overall, 12 species were identified as conservation priorities. The findings confirm that climate change is already reshaping semi-arid ecosystems in northwestern India, emphasizing the need for long-term monitoring, habitat conservation, and climate-adaptive management strategies to maintain butterfly diversity and ecosystem stability.

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