

Butterflies as Pollinators and Indicators of Ecosystem Health

*Dr. Priyanka Yadav¹, Kunjum Pradeep² and Prashanth Patil³

¹Assistant Professor (Zoology), Suraj PG Degree College, Gurugram, Haryana, India

²Ph.D. Scholar, Department of Entomology, Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya Gwalior, Madhya Pradesh, India

³M.Sc. Agricultural Entomology, Kerala Agricultural University, College of Agriculture Vellanikkara, Thrissur, Kerala, India

*Corresponding Author's email: dr.priyankayadav@hotmail.com

Butterflies belong to the order Lepidoptera and are among the most recognizable insects in terrestrial ecosystems. They occur in forests, grasslands, agricultural landscapes, wetlands, gardens and urban green spaces. Their ecological importance extends beyond their aesthetic value because they participate in plant-pollinator interactions, contribute to food webs and respond to changes in environmental conditions. Healthy ecosystems depend on interactions among plants, insects, microorganisms and other organisms.



Pollination supports the reproduction of many wild plants and contributes to agricultural production, while biodiversity helps maintain ecological processes and ecosystem resilience. Insect pollinator populations face several pressures, including habitat loss, agricultural intensification, pesticide exposure, pollution and climate change (Potts *et al.*, 2010). Thomas (2005) highlighted the importance of butterflies and other insect groups in monitoring changes in abundance and geographical distribution. However, butterflies should not automatically be considered universal indicators of ecosystem condition. Their ecological responses must be interpreted in relation to the habitat, species and environmental variables being studied (Fleishman & Murphy, 2009). This article discusses the role of butterflies in pollination, their significance as indicators of ecosystem health, the environmental factors influencing their populations and the conservation approaches required to maintain their ecological functions.

Butterflies as Pollinators

Mechanism of butterfly pollination

Pollination is the transfer of pollen grains from the anther to the stigma of a flower. This process enables fertilization and contributes to seed and fruit formation in flowering plants. Butterflies visit flowers primarily to obtain nectar, which provides energy for flight, movement and reproduction. While feeding, their bodies may come into contact with anthers and stigmas. Pollen grains adhering to their legs, body hairs, proboscis or other body surfaces may subsequently be transferred to another flower. Butterflies generally possess a long, coiled proboscis that enables them to obtain nectar from flowers of different shapes and depths. Their visual sensitivity and attraction to floral colours also influence flower selection. Floral characteristics such as colour, shape, scent, nectar availability and flowering period help determine which butterflies visit particular plants (Willmer, 2011).

Contribution to plant reproduction

Butterflies can contribute to the reproductive success of wild flowering plants by transferring pollen between flowers. This contribution may be particularly important for plants whose floral structures and nectar rewards attract butterflies.

Butterfly-mediated pollen transfer can support:

- Sexual reproduction in flowering plants.
- Genetic exchange between compatible plants.
- Seed production and the maintenance of plant populations.
- Reproduction of certain wild plants in natural and semi-natural habitats.
- Plant diversity and the persistence of plant–pollinator interactions.

The actual contribution varies with butterfly species, flower morphology, pollen placement, visitation frequency and the compatibility of pollen with the recipient plant. Consequently, the pollination effectiveness of butterflies should be evaluated for particular plant–pollinator relationships rather than assumed to be equal across all flowering plants (Willmer, 2011).

Butterfly–flower relationships

Butterflies and flowering plants exhibit ecological relationships shaped by floral resources and insect behaviour. Many butterflies visit a range of flowering plants, while some species show stronger preferences for particular floral resources. Flowering plants benefit when visiting butterflies transfer pollen, while butterflies obtain nectar that supports their energy requirements. These interactions can contribute to the functioning of plant–pollinator networks. Willmer (2011) discusses how floral morphology, visual signals, nectar rewards and pollinator behaviour influence pollination. Nevertheless, the relative importance of butterflies compared with bees, hoverflies and other pollinators differs among ecosystems and plant species.

Role in agricultural and natural ecosystems

Butterflies occur in agricultural landscapes, field margins, orchards, gardens and natural vegetation. They may contribute to the pollination of selected crops and wild plants, although their importance varies considerably among plant species. The broader importance of pollination services is well established, but the contribution of butterflies to the yield of an individual crop should be demonstrated through crop-specific research rather than inferred from butterfly abundance alone (Potts *et al.*, 2010; Willmer, 2011).

Butterflies as Indicators of Ecosystem Health

Concept of bioindicators

A bioindicator is an organism or group of organisms whose presence, absence, abundance, distribution or biological response provides information about a particular environmental condition. Butterflies are frequently used in ecological monitoring because they are relatively conspicuous, can be surveyed using standardized field methods and respond to changes in vegetation and habitat conditions. Their close association with host plants during the larval stage also links their populations to the availability and condition of vegetation. Butterfly monitoring can help researchers assess biodiversity patterns, habitat change and conservation outcomes. Thomas (2005) reviewed the value of butterflies and other insect groups for monitoring changes in abundance and distribution. Bonebrake *et al.* (2010) further emphasized the ecological complexity of tropical butterflies and the importance of understanding their species-specific responses.

Habitat quality and vegetation structure

Habitat quality is a major factor influencing butterfly diversity and abundance. Different species require different combinations of host plants, nectar sources, shelter, suitable microclimates and breeding sites. Habitats containing diverse native vegetation may support butterflies with different ecological requirements. Conversely, the removal of host plants, simplification of vegetation and destruction of breeding habitats can reduce the suitability of an area for particular species. Butterfly surveys can therefore help identify habitats that support specialized species, reveal changes in vegetation-associated communities and evaluate restoration efforts. However, high butterfly abundance does not always indicate high ecological quality. A disturbed habitat may favour a few widespread generalist species while supporting

fewer specialist species. Species composition and ecological requirements should therefore be considered alongside total abundance.

Biodiversity assessment

Butterflies can contribute to biodiversity assessments at local, landscape and regional scales. Researchers commonly record species richness, abundance, diversity and community composition to examine differences among habitats or changes over time. Species richness refers to the number of species recorded in a defined area, whereas abundance refers to the number of individuals observed. Community composition identifies which species are present and how their relative representation changes. Monitoring these parameters across forests, grasslands, agricultural fields and urban habitats can help reveal ecological differences among landscapes. Repeated surveys may also identify changes associated with habitat degradation or conservation interventions. Bonebrake *et al.* (2010) emphasized that tropical butterfly ecology is complex and that knowledge gaps can limit conservation decisions. Thus, biodiversity assessments should incorporate local ecological information and avoid assuming that patterns observed in one region apply universally.

Environmental pollution and contamination

Butterflies may provide information about certain forms of environmental contamination because they interact with vegetation and occupy different positions in terrestrial food webs. Pallottini *et al.* (2023) investigated trace-metal contamination in five butterfly species across nine sites in Italy's Terni valley. Their findings showed relationships between environmental contamination and concentrations of certain metals in butterfly tissues, although the strength of these relationships varied among species and sampling locations. This study demonstrates the potential of selected butterfly species for investigating specific environmental pollutants. It does not establish that all butterflies reliably measure all forms of pollution. The use of butterflies for contamination monitoring requires careful selection of species, standardized sampling, laboratory analysis and comparison with environmental measurements. Soil characteristics, host-plant accumulation, larval feeding habits and species mobility can influence contaminant concentrations.

Climate change and environmental change

Climate change can influence butterfly populations through changes in temperature, rainfall, seasonal conditions, host-plant distribution and flowering phenology. These changes may affect larval development, adult activity, survival, reproduction and geographical distribution. Some butterfly species may expand their ranges under changing climatic conditions, while others may decline when suitable habitats or climatic conditions become restricted. The direction and magnitude of these responses depend on species biology and regional conditions. Butterflies can therefore serve as useful components of long-term biodiversity monitoring. However, a change in butterfly abundance during one season may reflect short-term weather conditions rather than a persistent ecological trend. Long-term observations are necessary to distinguish natural fluctuations from sustained environmental change (Thomas, 2005; Bonebrake *et al.*, 2010).

Major Environmental Factors Affecting Butterfly Populations

Habitat loss and fragmentation

Conversion of natural vegetation into agricultural land, roads, buildings and industrial areas can remove host plants, nectar resources and breeding sites. Habitat fragmentation may isolate populations and reduce movement between suitable patches. Butterfly species with specialized host-plant requirements may be particularly vulnerable when their preferred vegetation disappears. Maintaining connected habitats and restoring native vegetation can help improve landscape suitability.

Pesticide exposure

Insecticides can affect butterflies through direct contact, contaminated vegetation, ingestion and exposure during sensitive life stages. Larvae may be particularly vulnerable when their host plants are treated with insecticides. The magnitude of the effect depends on the active ingredient, dose, formulation, exposure route, application timing and butterfly species.

Pesticide effects should therefore be evaluated using appropriate toxicological and field evidence. Integrated pest management, selective pest-control measures, avoidance of unnecessary applications during flowering and protection of non-crop vegetation can help reduce risks to non-target insects.

Loss of host plants and floral resources

Butterfly larvae depend on suitable host plants, whereas adults often require nectar and other resources. Removing native vegetation or eliminating flowering plants can reduce the availability of food and breeding sites. Landscapes that provide a sequence of flowering resources throughout the season may be more supportive than those offering flowers only during a short period. Conservation planning should also protect the specific host plants required by local butterfly species.

Pollution and urbanization

Industrial emissions, contaminated soils, intensive land use and urban development can alter butterfly habitats. Urban green spaces may support some widespread species, but highly simplified landscapes may lack the host plants and vegetation structure required by specialists. Pallottini *et al.* (2023) demonstrated that butterfly tissue concentrations of certain trace metals can reflect contamination in particular settings. Nevertheless, environmental assessments should combine biological observations with direct measurements of soil, water or air quality where appropriate.

Climate variability

Temperature, rainfall, drought and seasonal shifts can influence adult flight activity and the availability of host plants and nectar sources. Extreme conditions may also affect survival and reproduction. A reliable assessment should account for seasonal variation, weather conditions and differences in survey effort. Repeated observations across several years are particularly useful for identifying longer-term population trends.

Scientific Limitations of Butterflies as Bioindicators

Although butterflies have considerable value in conservation research, their use as indicators requires careful interpretation. First, butterfly species differ in their habitat requirements and responses to environmental stress. A species that responds strongly to forest disturbance may not be a suitable indicator of pesticide contamination or pollinator diversity. Second, butterfly populations naturally fluctuate with weather, season, migration, host-plant availability and reproductive cycles. These factors can complicate the interpretation of short-term observations. Third, butterflies cannot reliably represent the diversity of all other pollinators. Segre *et al.* (2023) compared butterflies, bees and hoverflies and found that butterfly richness did not reliably track bee richness across the studied sites and time periods. The authors highlighted floral-resource diversity as a useful additional measure for pollinator monitoring. Fourth, conspicuous and widespread species may be easier to record than rare or cryptic species. Sampling methods, observer expertise and the time of day can influence recorded diversity. Fleishman and Murphy (2009) emphasized that indicator species must be selected according to clearly defined environmental objectives and validated ecological relationships. Accordingly, butterflies are best used as one component of a broader monitoring programme rather than as a universal measure of ecosystem health.

Table 1. Butterfly-based indicators and their interpretation in ecosystem-health assessment. Prepared as a synthesis of Thomas (2005), Fleishman and Murphy (2009), Pallottini *et al.* (2023), and Segre *et al.* (2023).

Indicator parameter	What it can reveal	Important limitation
Species richness	Diversity of butterfly species	Influenced by season and sampling effort
Abundance	Relative numbers recorded	Weather and adult activity can affect counts
Community composition	Presence of specialist and generalist species	Requires reliable identification

Indicator parameter	What it can reveal	Important limitation
Host-plant diversity	Availability of larval resources	Plant presence does not guarantee successful breeding
Butterfly tissue contaminants	Exposure to selected pollutants	Species and contaminants differ in suitability
Floral-resource richness	Availability of flowering resources	Does not directly measure successful pollination

Monitoring Approaches for Butterfly Conservation

Effective monitoring requires standardized methods and repeated observations.

Transect surveys

A fixed-length transect can be established within the study area, and butterflies observed along the route can be recorded using a consistent protocol. Surveys should be conducted under suitable weather conditions and repeated at comparable times and intervals.

Species richness and abundance

Researchers can record the number of butterfly species and individuals observed during each survey. Comparing these measures across habitats and seasons helps identify ecological differences and changes over time.

Host-plant and floral-resource assessment

Recording host-plant availability, flowering-plant richness, flower abundance and vegetation structure helps explain patterns in butterfly occurrence. Segre *et al.* (2023) found that floral richness was strongly associated with the richness of butterflies, bees and hoverflies in their study system.

Pollution assessment

Where contamination is suspected, butterfly surveys may be combined with laboratory analysis of selected species and direct measurements of environmental samples. The choice of indicator species and contaminant must be appropriate to the research question.

Long-term monitoring

Repeated surveys over several seasons and years provide a stronger basis for identifying trends than isolated observations. Standardized methods, consistent sampling effort and records of weather and habitat conditions improve the reliability of comparisons (Thomas, 2005).

Conservation Strategies

The conservation of butterflies requires protection of both adult feeding resources and larval habitats.

1. Protect natural habitats: Conserve forests, grasslands, wetlands, field margins and other habitats that support butterfly populations.
2. Restore native flowering plants: Establish diverse native vegetation that provides nectar and pollen resources across different flowering periods.
3. Conserve larval host plants: Identify and retain the plant species required by local butterfly larvae.
4. Reduce pesticide risks: Promote integrated pest management, selective insecticides where necessary and practices that minimize exposure of non-target insects.
5. Improve landscape connectivity: Maintain vegetation corridors and habitat patches that facilitate movement between suitable areas.
6. Encourage community participation: Support butterfly gardens, citizen-science surveys, educational activities and local biodiversity monitoring.
7. Integrate multiple indicators: Combine butterfly records with bee and hoverfly surveys, floral-resource assessments, vegetation measurements and relevant environmental-quality data.
8. Strengthen research and monitoring: Establish long-term monitoring programmes that document seasonal changes, population trends and the outcomes of conservation interventions.

These measures can support butterfly conservation while contributing to the broader protection of plant–pollinator interactions and terrestrial biodiversity (Bonebrake *et al.*, 2010; Potts *et al.*, 2010).

Conclusion

Butterflies contribute to terrestrial ecosystems through flower visitation, pollen transfer, food-web interactions and their close association with host plants and vegetation. Their diversity, distribution and population responses can provide valuable information about habitat quality and selected environmental changes. Research on trace-metal contamination further demonstrates that appropriately selected butterfly species may contribute to targeted environmental monitoring. Nevertheless, butterfly presence or abundance alone cannot establish the overall health of an ecosystem. Their ecological responses vary among species and are influenced by weather, habitat structure, host plants and other environmental factors. Evidence also indicates that butterflies cannot consistently serve as substitutes for other pollinator groups. Ultimately, butterflies are valuable components of ecosystem-health assessment when their biological characteristics are understood and their monitoring results are interpreted within a broader ecological framework.

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