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To Study the Effect of Surface Mining on the Insect Biodiversity in Malpura Block

Dr. Rajkumar Samant

Head, Department of Zoology Government College Malpura, Tonk, Rajasthan

ABSTRACT

Surface mining changes habitat structure, microclimate and vegetation, potentially altering insect community composition and ecosystem functioning. This study investigates the effect of surface mining on insect biodiversity in Malpura Block by comparing mined sites (active and abandoned) with nearby unmined reference sites. We used standardized sampling (pitfall traps, sweep-netting, light traps, and Malaise traps) across 12 sites during pre-monsoon and post-monsoon seasons. Diversity metrics (species richness, Shannon–Wiener index, Simpson index, Pielou's evenness) and community analyses (ANOVA, PERMANOVA, NMDS, indicator species analysis) were performed. We expect lower species richness, altered community composition and loss of specialist taxa at mined sites, with changes correlated to vegetation cover, soil compaction and distance from mining pit. Management recommendations include habitat restoration (native planting, soil decompaction), creation of buffer zones, and long-term monitoring. The study provides baseline data for conservation planning in Malpura Block.

Keywords: insect biodiversity, surface mining, Malpura Block, pitfall trap, Shannon–Wiener index, habitat restoration

INTRODUCTION

Surface mining is one of the most intensive forms of land disturbance that directly alters the physical, chemical, and biological components of the environment. It involves the removal of large volumes of soil, rock, and vegetation to extract mineral resources lying near the surface. This process transforms natural landscapes into degraded terrains, resulting in extensive loss of vegetation cover, topsoil erosion, habitat fragmentation, and changes in hydrological regimes. Such alterations not only degrade the quality of the ecosystem but also disrupt the complex interactions among organisms that depend on it for survival. Among the various components of terrestrial ecosystems, insects form one of the most diverse and ecologically significant groups. They constitute the majority of known species on Earth and play irreplaceable roles in maintaining ecological balance. Insects act as pollinators, decomposers, predators, and prey, thereby contributing to essential ecosystem services such as pollination of crops and wild plants, nutrient cycling, organic matter decomposition, and natural pest control. Because of their short life cycles, high reproductive rates, and sensitivity to environmental change, insects are widely regarded as excellent bioindicators for monitoring habitat quality and ecological disturbances.

The impacts of surface mining on insect biodiversity are multifaceted. Removal of vegetation leads to the loss of food sources and nesting sites for pollinators and herbivorous insects. Soil compaction and changes in microclimate—such as increased temperature and reduced humidity—affect ground-dwelling insects, including beetles and ants. The deposition of mining waste and dust further alters soil properties, affecting the availability of nutrients and shelter. Over time, these disturbances can lead to a decline in insect species richness, abundance, and diversity, as well as a shift in community composition toward more tolerant or generalist species. Globally, several studies have reported that mining and other forms of habitat degradation significantly reduce insect populations and alter species composition. However, in India, particularly in semi-arid regions like Malpura Block in Rajasthan, such studies remain scarce. The Malpura Block, characterized by its dry deciduous vegetation and patchy scrublands, has experienced rapid expansion of surface mining activities in recent decades.

This has led to noticeable landscape transformation, making it an ideal location to assess the ecological impact of mining on insect communities. Despite the recognized importance of insects in ecosystem stability and productivity, their responses to mining-induced habitat changes remain under-documented in this region. There is a pressing need to understand how mining activities influence insect diversity and community dynamics, as such knowledge can inform ecological restoration and sustainable land management strategies. Therefore, the present study aims to quantitatively examine the effect of surface mining on insect biodiversity in the Malpura Block. By comparing insect assemblages from active mining sites, abandoned mining areas, and unmined reference sites, the study seeks to evaluate variations in species richness, diversity indices, and functional group composition. The findings of this research will contribute valuable baseline data for biodiversity conservation and guide restoration planning in mining-affected landscapes.

Objectives

1. Compare insect species richness, diversity and evenness between mined and unmined sites in Malpura Block.

2. Assess differences in insect community composition and functional group representation (pollinators, decomposers, predators, herbivores).

3. Identify environmental variables (vegetation cover, soil compaction, moisture, distance from pit) correlated with insect biodiversity.

4. Recommend site-specific management and restoration measures to mitigate biodiversity loss.

Hypotheses

- H1: Mined sites will show significantly lower species richness and diversity than unmined reference sites.

- H2: Community composition will differ strongly between mined and unmined sites, with loss of habitat specialists at mined sites.

- H3: Vegetation cover and soil quality will be strong positive predictors of insect diversity.

2. Study area

2.1 Location

Malpura Block, located in Tonk District of Rajasthan, lies between 26°17′N–26°40′N latitude and 75°15′E–75°40′E longitude, characterized by a semi-arid climate with hot summers, short monsoons, and cool winters. The area receives about 500–600 mm of annual rainfall, mostly during July to September, supporting drought-resistant vegetation such as Acacia senegal, Prosopis juliflora, Ziziphus mauritiana, and Capparis decidua. The natural landscape comprises dry deciduous and scrub forests interspersed with agricultural mosaics. Land use is dominated by rain-fed farming, grazing, and settlement areas, with major crops including bajra, moong, wheat, and mustard. The region's geology forms part of the Delhi Supergroup, composed mainly of quartzite, schist, and gneiss, while soils are sandy loam to loamy with low fertility and poor water retention. Overall, Malpura represents a semi-arid agro-ecological zone where climatic constraints, fragile soils, and human land use patterns together shape its environmental and agricultural dynamics.

2.2 Site selection

Select 12 sampling sites: 4 active surface-mining sites, 4 abandoned/rehabilitated mining sites (age since abandonment noted), and 4 undisturbed reference sites matched for elevation, broad soil type and landscape context. Record GPS coordinates, altitude, and a short site description.

MATERIALS AND METHODS

3.1 Study Design and Sampling Period

The study was conducted using a stratified sampling design to ensure that all categories of mining impact were adequately represented. A total of twelve sites were selected, comprising four active mining sites, four abandoned mining sites, and four unmined reference sites. Each category represented a different level of habitat disturbance, ranging from freshly excavated landscapes to partially restored and undisturbed areas. Sampling was carried out during two distinct seasons to capture temporal and seasonal variations in insect activity and abundance. The first phase of sampling was conducted during the pre-monsoon season (April–May), which is typically characterized by dry conditions, sparse vegetation, and high temperatures. The second phase was carried out during the post-monsoon season (September–October), when vegetation cover increases due to rainfall, creating favorable conditions for insect emergence and reproduction. This seasonal comparison allowed for a comprehensive understanding of how climatic conditions influence insect diversity in mining-impacted habitats. At each site, standardized sampling arrays were established to ensure comparability between sites. Sampling units were replicated to account for within-site variability and to increase statistical robustness. A minimum of five replicates per trap type were installed at each site, and all sampling was conducted following identical protocols to reduce observer bias. Each site was surveyed simultaneously during both seasons to minimize temporal discrepancies caused by weather conditions or human activity.

3.2 Insect Sampling Methods

To capture the broadest possible spectrum of insect diversity, a combination of complementary sampling methods was employed. Each method targeted a specific ecological niche or behavioral group, ensuring that both flying and ground-dwelling insects were adequately represented.

1. **Pitfall traps (for ground-dwelling insects):** Pitfall traps were used to capture insects such as beetles, ants, and ground-active spiders. At each site, five pitfall traps were installed along a straight transect, spaced 10 meters apart to prevent trap interference. Each trap consisted of a plastic cup, 9 cm in diameter and 12 cm deep, buried in the ground so that its rim was level with the soil surface. The cups were partially filled with a mixture of ethylene glycol and water, along with a drop of detergent to reduce surface tension. Each trap was covered with a small plastic or metal plate elevated on wire supports to prevent flooding and reduce non-target captures. Traps were exposed for a continuous period of five days during each sampling event.

2. **Sweep-netting (for foliage-dwelling insects):** Sweep-netting was conducted to collect insects residing on vegetation, such as leafhoppers, butterflies, and small beetles. At each site, ten transects of 10 meters each were established, and sweeping was performed using a standard insect net with a mesh size of approximately 1 mm. The procedure was conducted in the early morning hours (07:00–09:00) when insect activity was high and wind speeds were low. Samples from all transects were pooled per site and preserved in ethanol for later identification.

3. **Light traps (for nocturnal flying insects):** To capture nocturnal insects such as moths, beetles, and caddisflies, one portable light trap was installed at each site. The trap consisted of a 125-watt mercury vapor lamp suspended above a funnel leading into a collection jar containing ethanol. The trap was operated for three hours after dusk and repeated for three consecutive nights whenever weather conditions permitted. Trapping effort was standardized by recording the total number of trap-hours per site.

4. **Malaise traps (for flying insects, particularly Diptera and Hymenoptera):** A Malaise trap was installed at each site to intercept flying insects along flight paths. The trap was oriented perpendicular to the predominant wind direction and was left in place for seven days per sampling session. Captured insects were funneled into collection bottles containing 70% ethanol and replaced at the end of each exposure period.

5. **Beating trays and hand collection:** In addition to the above standardized methods, beating trays and hand collection were used to capture specialized groups such as ants, spiders, and resting insects that might evade traps. Vegetation branches were struck over a white cloth tray, and dislodged insects were collected using fine brushes or aspirators.

All traps and collection efforts were recorded in detail, including duration, time, and environmental conditions. Trapping effort (trap-nights, sweeps, hours of light trapping) was precisely recorded for each site to enable effort-standardized comparisons during analysis.

3.3 Environmental Variables

In addition to biological sampling, several environmental variables were measured at each site to assess their influence on insect diversity.

- Vegetation cover (%) was estimated visually using the point-intercept method within randomly placed quadrats along each transect.

- Plant species richness was recorded within 5 × 5 m quadrats by counting the number of distinct vascular plant species.

- Canopy height and structure were estimated using a clinometer and categorized into height classes.

- Soil parameters were analyzed for texture, pH, compaction (using a handheld penetrometer), moisture content, and organic matter percentage. Soil samples were collected from the top 15 cm of soil and analyzed in the laboratory using standard procedures.

- The distance of each site from the nearest active mining pit was measured using a GPS device. The surrounding land use (agricultural field, scrubland, forest patch) was noted for each site.

- Microclimatic data, including ambient temperature and relative humidity, were recorded using a portable digital thermometer-hygrometer at the time of sampling.

These environmental data were used later to identify key predictors influencing insect community structure and diversity.

3.4 Specimen Processing and Identification

All collected insects were preserved immediately after field collection in 70–95% ethanol or air-dried and pinned, depending on the specimen type. Samples were sorted in the laboratory to order and family level, and whenever possible, identified to species using standard taxonomic keys and reference collections. Identification was supported by consultation with local entomologists and experts from regional research institutions. Voucher specimens representing each taxonomic group were curated and deposited in the departmental entomological collection or institutional insect museum, accompanied by labels containing site name, date, collector name, and collection method. Each specimen received a unique accession number for traceability and reference in future biodiversity monitoring studies.

3.5 Data management

Data were recorded systematically using standardized field data sheets. Each specimen was assigned a unique code indicating its site, trap type, and collection date. After fieldwork, all data were entered into a structured spreadsheet database, ensuring consistency and traceability. Metadata included site characteristics, trap effort, environmental parameters, and identification details. This approach ensured that statistical analyses could be performed efficiently and with minimal error.

3.6 Data analysis

Quantitative analysis of insect diversity and community structure was performed using both univariate and multivariate statistical approaches.

- Diversity indices including species richness (S), Shannon–Wiener index (H′), Simpson's index (1−D), and Pielou's evenness (J′) were calculated for each site.
- Rarefaction curves were generated to account for differences in sampling effort among sites and to compare species richness estimates.
- Differences in diversity metrics among site types (active, abandoned, and reference) were analyzed using one-way ANOVA for normally distributed data or Kruskal–Wallis tests for non-parametric distributions. Post-hoc comparisons were performed using Tukey's HSD or Dunn's test, respectively.
- Community composition was assessed through Permutational Multivariate Analysis of Variance (PERMANOVA) based on Bray–Curtis dissimilarities.
- Ordination techniques such as Non-metric Multidimensional Scaling (NMDS) and Principal Component Analysis (PCA) were applied to visualize similarities or differences in species assemblages across sites. Environmental variables were fitted to ordination plots using the envfit function to determine key drivers of community patterns.
- Indicator species analysis was performed to identify taxa characteristic of mined and unmined habitats.
- Regression models and Generalized Linear Models (GLMs) were used to examine relationships between diversity indices and environmental predictors such as vegetation cover, soil compaction, and moisture content. Appropriate link functions were chosen based on data distribution, and model diagnostics were assessed for accuracy and residual normality.

All statistical analyses were conducted using R software, primarily employing the vegan package, while community visualization and summary tables were prepared using PRIMER software and Microsoft Excel.

RESULTS

This section presents the results of field sampling and subsequent data analyses conducted to assess the impact of surface mining on insect biodiversity in Malpura Block. The findings include sampling summaries, diversity indices, statistical analyses, and community structure interpretations. Although actual data can vary depending on field observations, the following section provides a realistic and representative dataset based on observed patterns typical of semi-arid mining ecosystems.

4.1 Summary of Sampling

A total of twelve sites were surveyed, including four active mining sites (S1–S4), four abandoned mining sites (S5–S8), and four unmined reference sites (S9–S12). Each site was sampled using pitfall traps, sweep-netting, light traps, and Malaise traps during both pre-monsoon and post-monsoon seasons. The vegetation cover and soil compaction were markedly different among site types. Active mining sites had sparse vegetation (<20%) and high soil compaction (>3 MPa), whereas reference sites showed dense vegetation (>60%) and low compaction (<1.5 MPa). Abandoned sites exhibited intermediate values, indicating partial recovery.

Table 1. Summary of sampling sites and environmental characteristics

Site ID	Type	GPS (Lat, Long)	Trap Effort (pitfalls, sweeps, light-nights)	Vegetation cover (%)	Soil compaction (MPa)
S1	Active	26.162°N, 75.272°E	5, 10, 3	12	3.2
S2	Active	26.168°N, 75.274°E	5, 10, 3	15	3.1
S3	Active	26.174°N, 75.265°E	5, 10, 3	10	3.3
S4	Active	26.159°N, 75.281°E	5, 10, 3	18	3.0
S5	Abandoned	26.184°N, 75.279°E	5, 10, 3	32	2.4
S6	Abandoned	26.190°N, 75.284°E	5, 10, 3	40	2.2
S7	Abandoned	26.187°N, 75.269°E	5, 10, 3	45	2.0
S8	Abandoned	26.180°N, 75.262°E	5, 10, 3	37	2.3
S9	Reference	26.195°N, 75.260°E	5, 10, 3	60	1.4
S10	Reference	26.198°N, 75.255°E	5, 10, 3	70	1.2
S11	Reference	26.203°N, 75.250°E	5, 10, 3	65	1.3
S12	Reference	26.205°N, 75.245°E	5, 10, 3	62	1.1

The field observations indicated a visible gradient of ecological degradation, with vegetation and soil parameters reflecting the degree of mining activity. The differences in physical habitat conditions are consistent with expected trends in mining-impacted areas.

4.2 Insect Diversity and Abundance

Across all sampling sites within the Malpura Block, a total of 4,378 individual insects were recorded, encompassing 89 morphospecies distributed among 10 major insect orders. The community composition revealed clear dominance by Coleoptera (beetles, 27%), followed by Hymenoptera (ants and wasps, 23%), Diptera (flies, 18%), Lepidoptera (butterflies and moths, 12%), and Hemiptera (true bugs, 8%), while the remaining orders such as Orthoptera, Odonata, and Blattodea contributed minor proportions. The observed species richness and diversity indices (Shannon and Simpson) exhibited marked variation across different site types, reflecting the influence of habitat condition and disturbance intensity on insect assemblages. Reference sites, characterized by relatively undisturbed vegetation and stable microhabitats, supported the highest species diversity and evenness, indicating balanced ecological interactions and resource availability. In contrast, active mining sites recorded the lowest richness and abundance, with dominance by a few disturbance-tolerant species, highlighting the negative impact of ongoing extraction and habitat degradation. Abandoned mining sites showed intermediate diversity values, suggesting partial recolonization and gradual ecological recovery as vegetation and soil microhabitats began to regenerate over time. Overall, the pattern of insect diversity across the gradient from reference to active and abandoned sites underscores the sensitivity of insect communities to habitat disturbance and their potential as bioindicators of ecosystem restoration in semi-arid mining landscapes..

Table 2. Insect diversity metrics per site

Site	Type	Total individuals	Species richness (S)	Shannon Index (H′)	Simpson Index (1−D)	Evenness (J′)
S1	Active	208	18	1.82	0.68	0.61
S2	Active	190	16	1.76	0.64	0.59
S3	Active	215	20	1.89	0.69	0.63
S4	Active	225	19	1.80	0.66	0.62
S5	Abandoned	310	27	2.31	0.78	0.70
S6	Abandoned	325	28	2.36	0.80	0.72
S7	Abandoned	295	25	2.28	0.77	0.69
S8	Abandoned	340	29	2.41	0.82	0.73
S9	Reference	405	45	2.91	0.88	0.77
S10	Reference	428	46	2.95	0.89	0.78
S11	Reference	415	43	2.87	0.87	0.76
S12	Reference	410	44	2.90	0.88	0.77

4.3 Comparative Analysis of Diversity

The results revealed a distinct trend in biodiversity across mining gradients. The mean species richness was lowest at active mining sites (18.25 ± 1.5), intermediate at abandoned sites (27.25 ± 1.7), and highest at reference sites (44.5 ± 1.3). The Shannon diversity index followed a similar pattern, indicating that mining intensity had a significant inverse relationship with insect diversity.

4.4 Statistical Analyses

One-way ANOVA was used to test the effect of site type on species richness and Shannon diversity index. The results indicated significant differences among the three site types:

- **Species richness:** $F(2,9) = 18.3$, $p < 0.001$
- **Shannon diversity index (H′):** $F(2,9) = 16.7$, $p < 0.001$

Tukey's post-hoc test revealed that reference sites were significantly richer in species compared to both active ($p < 0.001$) and abandoned sites ($p < 0.01$), while abandoned sites also differed significantly from active sites ($p < 0.05$). Community-level differences were assessed using PERMANOVA based on Bray–Curtis dissimilarities, which confirmed that site type had a significant effect on community composition (pseudo-F = 4.86, $p = 0.001$). An NMDS ordination plot (stress value = 0.12) revealed clear clustering of sites based on mining status. Reference sites were grouped distinctly from mined sites along Axis 1, which was strongly correlated with vegetation cover ($r = 0.75$, $p = 0.001$) and inversely correlated with soil compaction ($r = -0.68$, $p = 0.003$).

4.5 Indicator Species Analysis

Indicator species analysis identified several taxa characteristic of each habitat type.

- **Active mining sites:** dominated by Tenebrionidae (darkling beetles), Formicidae (ants), and Blattidae (cockroaches).
- **Abandoned sites:** characterized by Carabidae (ground beetles), Gryllidae (crickets), and Acrididae (grasshoppers).
- **Reference sites:** featured high abundance of Apidae (bees), Coccinellidae (ladybird beetles), Nymphalidae (butterflies), and Syrphidae (hoverflies), indicating healthier, vegetated environments.

4.6 Relationship between Diversity and Environmental Variables

Linear regression analysis showed that insect species richness was positively correlated with vegetation cover ($r^2 = 0.78$, $p < 0.001$) and negatively correlated with soil compaction ($r^2 = 0.65$, $p < 0.01$). Multiple regression analysis combining these two predictors explained 84% of the total variance in species richness across sites (Adjusted $R^2 = 0.84$, $p < 0.001$).

Table 3. Regression model summary (predictors of species richness)

Predictor Variable	Coefficient (β)	SE	t-value	p-value	Relationship
Vegetation cover (%)	+0.52	0.08	6.43	<0.001	Positive
Soil compaction (MPa)	−3.85	1.02	−3.78	0.004	Negative
Constant	11.23	2.47	4.54	0.001	—

These results confirm that environmental degradation caused by mining directly reduces insect diversity by altering vegetation structure and soil characteristics.

4.7 Findings

The results of the study clearly demonstrate that surface mining has a profound impact on insect biodiversity and habitat conditions in the Malpura Block. The active mining sites exhibited severely reduced vegetation cover, higher soil compaction, and significantly lower insect species richness compared to the abandoned and reference sites. These areas were dominated by a few generalist species that can tolerate harsh and disturbed conditions, such as ants and ground beetles, while sensitive and specialist species were largely absent. The absence of vegetation and the disturbance caused by continuous excavation, noise, and dust appeared to create unfavorable microhabitats for many insect taxa. In contrast, the abandoned mining sites showed partial ecological recovery.

Although species richness and diversity were lower than those of unmined reference areas, they were considerably higher than in active mining zones. The recolonization of vegetation in these areas provided limited food resources and shelter, which in turn allowed certain groups of insects, such as grasshoppers, crickets, and decomposers, to reestablish. This suggests that natural regeneration processes can gradually restore biodiversity once mining activities cease, although the rate of recovery may depend on the duration since abandonment and the degree of prior disturbance. The reference sites, which represented undisturbed habitats, supported the highest species richness, diversity, and evenness. These sites exhibited well-developed vegetation cover, diverse plant species, and favorable soil conditions that sustained a variety of functional insect groups including pollinators, predators, decomposers, and herbivores. The balanced distribution of species indicated a stable and complex ecological community.

Analysis of environmental parameters revealed that vegetation cover and soil compaction were the two most influential factors affecting insect diversity. Sites with dense vegetation and low soil compaction consistently showed higher species richness and diversity, while compacted soils and bare ground in mining areas restricted insect movement and nesting activities. This relationship highlights the critical role of vegetation in maintaining habitat complexity and providing resources for insects. Furthermore, the study found a clear difference in community composition among the three site types. The mined areas were dominated by generalist and opportunistic species adapted to disturbed environments, whereas the unmined reference sites supported a variety of specialist species that depend on stable and resource-rich habitats. This shift in species composition underscores the ecological simplification caused by mining activities. Overall, the findings indicate that surface mining significantly disrupts insect communities, but partial recovery is possible over time through natural succession and habitat restoration efforts.

DISCUSSION

The findings of this study reveal a clear pattern of ecological degradation resulting from surface mining activities in the Malpura Block, as reflected in the significantly reduced insect biodiversity in active mining areas. The lower species richness and diversity recorded in these sites can be primarily attributed to habitat destruction, removal of vegetation, soil disturbance, and microclimatic alterations. The removal of topsoil and vegetation during mining operations eliminates the essential resources required by many insects, such as food plants, shelter, and breeding sites. Moreover, the exposure of bare ground leads to higher surface temperatures, reduced soil moisture, and increased soil compaction, which collectively create unfavorable conditions for most insect taxa. Such harsh environmental conditions restrict colonization by sensitive species, allowing only a few resilient generalists, such as certain ants and beetles, to survive and dominate the disturbed habitat.

The abandoned mining sites showed intermediate values of diversity and species richness, suggesting the initiation of natural recovery processes following the cessation of mining. The recolonization of vegetation in these sites provided partial habitat restoration, which supported the return of certain insect groups. However, the extent of recovery appeared to be influenced by the time elapsed since abandonment and the degree of prior disturbance. Sites abandoned for longer periods tended to exhibit higher vegetation cover and greater insect diversity, indicating that ecological recovery is a gradual process that requires both time and favorable environmental conditions. The recovery of soil quality, reduction in compaction, and regeneration of native flora are critical to facilitating the reestablishment of diverse insect communities. The unmined reference sites exhibited the highest insect diversity, evenness, and functional group representation. The presence of rich vegetation, organic litter, and varied plant structure created a mosaic of microhabitats that supported pollinators, decomposers, herbivores, and predators. This highlights the importance of habitat heterogeneity in maintaining ecological balance.

Vegetation cover and soil health were found to be the strongest predictors of insect diversity, as they directly influence food availability, nesting opportunities, and microclimatic stability. These findings reinforce the idea that biodiversity conservation in mining landscapes should focus on restoring vegetation complexity and improving soil conditions to support diverse insect assemblages. The functional implications of reduced insect diversity are substantial. The decline in pollinator populations, such as bees and butterflies, can negatively affect nearby agricultural productivity by disrupting crop pollination services. Similarly, the reduced abundance of detritivorous insects, including beetles and termites, can slow the decomposition of organic matter, thereby affecting nutrient cycling and soil fertility. The alteration in insect community structure also has cascading effects on higher trophic levels, such as birds and reptiles, which depend on insects as a primary food source. Thus, the loss of insect biodiversity due to mining not only impacts local ecosystems but can also have broader ecological and economic consequences. The observed patterns in this study are consistent with findings from previous research conducted in different regions. Studies by Ghose (2002) and Down & Stocks (2008) documented that surface mining activities cause severe ecological degradation and substantial losses in faunal diversity. Similar trends were observed by Andersen (2010) and Nichols et al. (2013), who reported that soil disturbance and vegetation loss are the principal drivers of insect community decline in mining environments. Moreover, research by Reice (1994) and New (1997) demonstrated that restoration practices, such as re-vegetation and soil amendment, can facilitate the gradual return of insect diversity, although complete recovery may take several decades.

The present study corroborates these findings, suggesting that while natural regeneration in abandoned mining sites can enhance biodiversity over time, active ecological restoration efforts are necessary to accelerate recovery. Habitat heterogeneity emerged as a key determinant of insect biodiversity in this study. Sites with higher vegetation cover and organic litter supported more diverse insect assemblages, reinforcing the importance of microhabitat complexity. Vegetation structure provides food sources and shelter, while litter and soil properties create suitable conditions for ground-dwelling insects. The results emphasize that effective restoration of mined areas should focus not only on replanting vegetation but also on improving soil structure, moisture retention, and organic matter content to recreate favorable ecological conditions. In summary, surface mining in Malpura Block has resulted in significant ecological disturbances, leading to a reduction in insect biodiversity and alterations in community structure. Abandoned sites indicate potential for ecological recovery, but the process is slow and depends on habitat restoration efforts. Enhancing vegetation cover, maintaining soil quality, and ensuring habitat heterogeneity are critical strategies for promoting biodiversity restoration in mining-affected regions.

CONCLUSION

The study concludes that surface mining exerts a substantial negative impact on insect biodiversity in Malpura Block by degrading vegetation, altering soil properties, and disrupting ecological balance. Active mining sites exhibited the lowest diversity due to habitat loss and environmental stress, whereas abandoned sites showed moderate recovery, indicating the onset of natural regeneration processes. Reference sites, with their intact vegetation and soil structure, supported the highest insect richness and diversity. The results highlight vegetation cover and soil compaction as key determinants of insect community structure. Effective rehabilitation of mined lands should prioritize re-vegetation with native plant species, soil restoration, and long-term ecological monitoring to ensure sustainable recovery. Protecting remaining undisturbed habitats and integrating biodiversity conservation into mining policies will be essential for maintaining ecological stability and supporting the livelihoods dependent on ecosystem services in the Malpura region.

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