



Plant Archives

Journal homepage: <http://www.plantarchives.org>

DOI Url : <https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.042>

ENHANCING INSECT-MEDIATED ECOSYSTEM SERVICES: POLLINATION AND DECOMPOSITION INTERVENTIONS FOR FOREST PRODUCTIVITY

Kamlesh Bali, R.K. Gupta and Ranjana Bali*

Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha - 180 009, J.&K., India.

*Corresponding author E-mail : baliranjana3@gmail.com

(Date of Receiving-29-05-2025; Date of Acceptance-08-08-2025)

ABSTRACT

Insects are vital to ecosystems, contributing significantly to processes like pollination and organic matter breakdown. However, their populations are under increasing threat from habitat degradation, climate change and human-induced disturbances. This study evaluated how habitat improvement strategies such as installing artificial nests, establishing butterfly gardens and planting indigenous flowering species, affect pollinator diversity and insect-driven decomposition in forest areas of the northwestern Himalayas. Conducted from March 2022 to December 2023 in the Jammu region, the research compared sites with these interventions to untreated control areas. The results revealed notable gains in insect populations within enhanced habitats, including increases in honey bees (37.1%), butterflies (29.5%), solitary bees (18.9%) and megachilid bees (39.5%). Additionally, a strong positive relationship was observed between insect activity and biomass decomposition with the highest decomposition scores (up to 7.0) occurring at colonization levels of 12 and showing minimal variability. In contrast, lower insect presence corresponded to slower and inconsistent decomposition. These outcomes highlight the potential of cost-effective, nature-based enhancements to support insect biodiversity and nutrient recycling. The study emphasizes the need to adopt such strategies within forest and land-use planning to strengthen ecological sustainability and resilience.

Key words : Pollinators, Biomass decomposition, Habitat enhancement, Megachilid bees, Ecosystem services.

Introduction

Insects are integral to sustaining ecosystem functionality, primarily through essential services such as pollination and decomposition (Verma *et al.*, 2023). These functions are critical for ensuring plant reproductive success, nutrient turnover and the long-term viability of food production systems. Among insect pollinators, solitary bees and butterflies are particularly noteworthy due to their effectiveness in facilitating pollen transfer. By collecting nectar and pollen, they mediate the movement of pollen between flowers, a process that underpins fruit and seed formation (Potts *et al.*, 2010). Solitary bees, in particular, are often more effective than honey bees in certain ecological contexts, as they display high floral fidelity, visiting primarily one plant species per foraging bout, and tend to make more flower visits per trip (Mukhtar *et al.*, 2023). Despite their ecological significance, pollinator populations have been declining

globally. Key drivers include habitat loss and fragmentation, excessive pesticide application, environmental pollution and shifting climatic patterns (Boyle *et al.*, 2025). The IPBES (2016) global assessment reported that more than 40% of pollinating insects, including many bee and butterfly species, face extinction risks. This decline has far-reaching consequences, not only for biodiversity but also for food production, as approximately 75% of major crop species depend to some extent on animal pollination (Klein *et al.*, 2007). In light of these challenges, conservation strategies increasingly emphasize habitat improvement to bolster pollinator populations. Measures such as planting flower-rich strips, reducing chemical inputs, and installing artificial nesting structures have shown positive effects (Mukhtar *et al.*, 2023). For example, Tuell *et al.* (2008) documented increased native bee and butterfly abundance along floral-enriched field margins. Similarly, MacIvor and Packer

(2015) demonstrated that urban artificial nesting sites successfully attracted diverse solitary bee assemblages, underscoring the efficacy of simple, cost-effective interventions in enhancing pollinator presence even in disturbed or anthropogenic settings.

In addition to pollination, insects are also central to decomposition processes (Galante and Marcos-Garcia, 2023). Various taxa, including beetles, ants, and flies, play active roles in the degradation of organic matter, promoting nutrient cycling and enhancing soil health. These decomposer insects interact with microbial communities to accelerate nutrient mineralization, contributing to ecosystem productivity (Ulyshen, 2016). High insect diversity has been linked to faster decomposition rates; for instance, Yang and Gratton (2014) reported increased litter decomposition in agricultural systems with greater insect activity. Although the individual roles of pollinators and decomposers are well documented, research integrating both functional groups within the same ecological framework remains limited. Evaluating how habitat improvements influence these multiple insect-mediated services is critical for the development of comprehensive ecosystem management strategies. The present study investigates the effects of habitat enrichment, via artificial nesting structures and native flowering vegetation, on the abundance and activity of both pollinator and decomposer communities.

Materials and Methods

Study area

The present investigation was conducted across forest ecosystems of the northwestern Himalayas, with a focus on documenting insect-mediated ecosystem services, particularly pollination and biomass decomposition. The study was carried out between March 2022 and December 2023 in representative forest areas spanning the Jammu region, characterized by varied topography, climate and vegetation. Sites were stratified based on habitat conditions into intervention zones, where artificial nesting sites and butterfly parks were established and non-intervention zones, representing natural conditions without enhancement measures. These areas included forest clearings, ecotonal boundaries, riparian belts, and semi-disturbed woodlands.

Pollinator enhancement Interventions

To assess the effect of targeted conservation measures on pollinator populations, a series of habitat enhancement strategies were implemented. These included the installation of artificial nesting structures for solitary bees, establishment of butterfly parks and planting of native flowering plant species. Each intervention plot

consisted of ten focal plants surrounded by nesting or flowering resources designed to attract pollinators. Adjacent control plots of similar size and vegetation composition were maintained without any interventions. Pollinators were observed on ten randomly selected plants per plot. Observations were made during peak activity hours (0900–1200 hrs) under favourable weather conditions. The number of individual insects visiting flowers was recorded visually, and mean abundance was calculated per 10 plants for each insect group.

Insect Colonization and Biomass Decomposition assessment

To investigate the role of insects in forest biomass decomposition, decomposing organic matter was monitored across natural forested patches. Each decomposition site was categorized based on the level of insect colonization, determined by direct observation of insect activity indicators such as frass deposits, oviposition marks, larval tunnelling, and adult emergence holes. Colonization intensity was ranked on a scale from 1 to 12. At each site, the extent of decomposition was assessed using a semi-quantitative index ranging from 1 (least decomposed) to 7 (fully decomposed), based on standardized criteria including visual deterioration, fragmentation, fungal growth and physical collapse of the material.

Statistical analysis

Data were analyzed using IBM SPSS Statistics (version 20). One-way analysis of variance (ANOVA) was conducted to assess differences in mean values among the treatment groups. Where significant differences were found, Tukey's Honestly Significant Difference (HSD) test was applied for post hoc comparisons at a significance level of $p < 0.05$.

Results

Pollinator Abundance in response to Habitat interventions

Habitat enhancement interventions significantly increased the abundance of pollinators across all groups studied. As shown in Table 1, the average number of honey bees per 10 plants significantly increased from 2.13 ± 0.43 in non-intervention sites to 5.73 ± 0.79 in plots with artificial nesting and flowering resources, marking a 37.12% increase. Butterfly populations rose from 4.68 ± 0.54 to 15.89 ± 2.13 individuals per 10 plants, reflecting a 29.45% increase. Solitary bees exhibited a marked response to artificial nesting sites, with their mean abundance rising from 2.50 ± 0.58 in untreated plots to

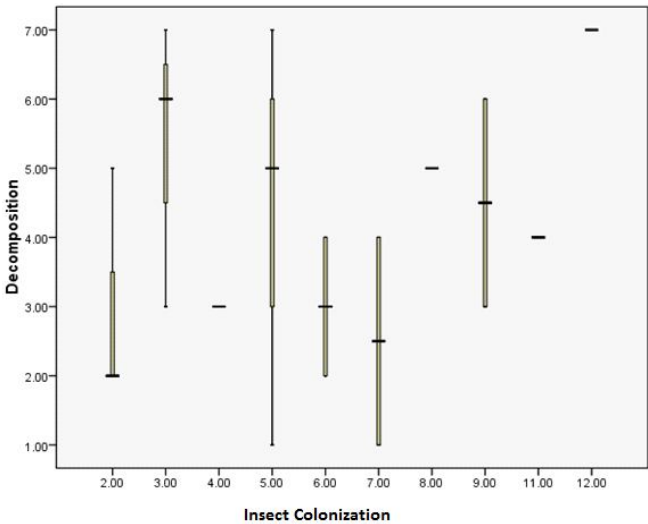


Fig. 1 : Relationship between insect colonization and decomposition rate across sampling units. [Each box indicates the interquartile range, with median lines marked inside the boxes and whiskers extending to the minimum and maximum values].

Table 1 : Impact of habitat interventions on pollinator abundance.

Pollinator group	With intervention*	Without intervention*	% increase
Honey bees	5.73 ±0.79 ^b	2.13±0.43 ^a	37.1%
Butterflies	15.89 ±2.13 ^b	4.68±0.54 ^a	29.5%
Solitary bees	13.20 ±3.08 ^b	2.50±0.58 ^a	18.9%
Megachilid bees	9.25±2.01 ^b	3.65±1.03 ^a	39.5%

Mean ± SD of individuals observed per 10 plants, ^{a, b}: Different superscript letters indicate statistically significant differences between treatments at p < 0.05 based on t-test.

13.2 ± 3.08 in treated plots. This corresponds to an 18.93% increase, although the variability was higher, as indicated by larger standard errors. Similarly, Megachilid bees, which include many cavity-nesting and pollen-collecting species, showed a strong response to interventions. Their abundance significantly increased from 3.65 ± 1.03 to 9.25 ± 2.01 per 10 plants, resulting in the highest percent increase (39.46%) among all groups.

Decomposition of Forest Biomass as influenced by Insect Colonization

The box plot (Fig. 1) illustrates the relationship between insect colonization levels and decomposition scores across different forest sites. A general upward trend in decomposition scores is evident as insect colonization increases, indicating a positive association between insect activity and biomass degradation. At low colonization levels (2–3), decomposition scores remained modest (mean scores between 2.0 and 3.0), suggesting

limited breakdown of forest debris under low insect presence. As colonization intensity increased (levels 5–9), decomposition scores became more variable, with wider interquartile ranges and longer whiskers. This variation may be attributed to differences in species composition (e.g., dominance of wood-boring vs. soft-tissue decomposers), microclimatic factors, or substrate quality. Notably, at colonization level 12, decomposition reached its maximum score (7.0), with minimal variance, indicating consistent and efficient biomass breakdown when insect activity was highest. The compactness of the box at this level further reflects a strong, uniform response across replicates. The results clearly show that insect colonization accelerates the decomposition of forest biomass, supporting the role of detritivores, scavengers, and saproxylic insects in nutrient cycling and organic matter turnover.

Discussion

The present study underscores the critical role of insect-mediated ecosystem services, particularly pollination and decomposition, in maintaining forest health and productivity. The results clearly demonstrate that habitat interventions, such as butterfly parks, artificial nesting sites, and enrichment with flowering plants, can significantly enhance pollinator abundance across multiple functional groups. Additionally, insect colonization was positively correlated with forest biomass decomposition, reinforcing the importance of insect diversity in ecosystem functioning.

Pollinator enhancement through Habitat interventions

Habitat management strategies led to a substantial increase in pollinator populations, especially honey bees, butterflies, solitary bees and Megachilid bees. This is consistent with findings from previous studies indicating that structural habitat complexity and floral diversity are key determinants of pollinator abundance and diversity (Neumann *et al.*, 2024; De Schuyter *et al.*, 2025). Artificial nesting structures serve as surrogate microhabitats that accommodate cavity-nesting bees such as Megachilidae, which often suffer from habitat fragmentation and the loss of nesting substrates (Mukhtar *et al.*, 2023). The marked increase in Megachilid bee populations (39.5%) highlights their dependency on such artificial habitats and suggests the potential for scaling up nest-site provisioning to conserve functionally significant pollinator groups. Butterflies also responded positively to the creation of butterfly parks and enrichment planting. These interventions not only increased nectar availability but also improved larval host plant resources,

which are essential for supporting complete butterfly life cycles (Bonebrake *et al.*, 2010). The near-tripling of butterfly numbers supports the notion that targeted habitat enhancements can rapidly increase invertebrate biodiversity in forest edges and transitional habitats (Öckinger and Smith, 2007). Furthermore, the increase in solitary bees, though slightly lower in magnitude, is ecologically significant. Solitary bees contribute disproportionately to pollination in forest ecosystems due to their foraging efficiency and floral fidelity (Maccagnani and Sgolastra, 2020). Their elevated presence in treated plots aligns with findings from tropical and temperate regions, where simple interventions such as floral strips and artificial nests have led to increased solitary bee abundance and subsequent improvements in fruit set and seed yield (Feltham *et al.*, 2015 and Rahimi *et al.*, 2021).

Insect Colonization and Biomass decomposition

Insects also play a vital role in detritus processing and nutrient cycling, a service that is often underappreciated in conservation planning. The present findings reveal a strong positive relationship between insect colonization levels and forest biomass decomposition scores. As insect abundance increased, decomposition became both more efficient and more consistent, particularly at higher colonization levels where decomposition scores peaked with minimal variation. These results corroborate studies showing that saproxylic insects such as beetles, ants and flies significantly enhance decomposition by physically breaking down organic matter and facilitating microbial colonization (Ulyshen, 2016; Seibold *et al.*, 2021). The observed variability in decomposition scores at intermediate colonization levels could reflect differences in the composition of insect assemblages, substrate moisture, or microclimatic conditions (Campobasso *et al.*, 2001). At low colonization densities, the lower and more variable decomposition suggests a weak or inconsistent decomposer community. Such patterns are particularly relevant in the context of climate change and habitat fragmentation, both of which can alter decomposer populations and reduce litter processing rates (Opdam and Wascher, 2004). Importantly, the stable and maximal decomposition at the highest colonization level (12 insects per plant) emphasizes the resilience and functional reliability of diverse insect communities. This aligns with the concept of functional redundancy and the insurance hypothesis, which posits that species-rich communities are more likely to maintain ecosystem processes under fluctuating conditions (Eisenhauer *et al.*, 2023).

Conservation implications

The results of this study have strong implications for biodiversity conservation and forest management. Enhancing habitat complexity and restoring microhabitats for pollinators and decomposers are low-cost, scalable strategies that can be integrated into participatory forest management plans. Moreover, these findings support the growing body of evidence that conserving insect biodiversity is essential not only for the preservation of species per se but also for the continued delivery of critical ecosystem services (Duffus *et al.*, 2023). Given the threats posed by climate change, deforestation and land-use change in Himalayan forests, adaptive management strategies that promote insect-friendly habitats can buffer ecosystems against biodiversity and service loss. Continued monitoring and expansion of such interventions across altitudinal gradients and habitat types are needed to develop regionally tailored conservation practices.

Conclusion

This study demonstrates that habitat interventions significantly boost pollinator abundance, especially among solitary bees and butterflies, and enhance insect-mediated forest biomass decomposition. Artificial nesting substrates and increased floral resources proved effective in attracting key pollinator groups, while higher insect colonization directly correlated with faster decomposition rates. These findings highlight the dual ecological benefits of targeted habitat management in promoting pollination and nutrient cycling, reinforcing the role of insects in sustaining ecosystem functions and supporting biodiversity-based conservation strategies.

Acknowledgement

The authors gratefully acknowledge the Department of Biotechnology (DBT), for fully funding and sponsoring the ongoing project (PR 39667) under which this research was carried out. We also extend our sincere thanks to Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu (SKUAST-J), Chatha, for providing the necessary infrastructure and institutional support.

Funding

This study was conducted as part of the ongoing DBT-sponsored project (PR 39667) at SKUAST-Jammu. The work was fully funded by the Department of Biotechnology (DBT), whose financial support is gratefully acknowledged.

Conflict of interest

Authors have no conflicts to declare

References

- Bonebrake, T., Ponisio L., Boggs C.L. and Ehrlich P.R. (2010). More than just indicators: A review of tropical butterfly ecology and conservation. *Biological Conservation*, **143**(8), 1831-1841.
- Boyle, M.J.W., Bonebrake T.C., Dias da Silva K., Dongmo M.A.K., Franca F.M., Gregory N., Kitching R.L., Ledger M.L., Lewis O.T., Sharp A.C., Stork N.E., Williamson J. and Ashton L.A. (2025). Causes and consequences of insect decline in tropical forests. *Nat. Rev. Biodivers.*, **1**, 315–331.
- Campobasso, C.P., Di Vella G. and Intronà F. (2001). Factors affecting decomposition and Diptera colonization. *Forensic Sci. Int.*, **120**(1–2), 18–27.
- De Schuyter, W., De Smedt P., Vanroy T., Baeten L. and Verheyen K. (2025). The effect of forest structural complexity on wild pollinator communities. *Biodiversity and Conservation*, **34**, 2697–2714.
- Duffus, N.E., Echeverri A., Dempewolf L., Noriega J.A., Furumo P.R. and Morimoto J. (2023). The Present and Future of Insect Biodiversity Conservation in the Neotropics: Policy Gaps and Recommendations. *Neotrop Entomol.*, **52**(3), 407–421.
- Eisenhauer, N., Hines J., Maestre F.T. and Rillig M.C. (2023). Reconsidering functional redundancy in biodiversity research. *NPJ Biodiversity*, **2**, 9. <https://doi.org/10.1038/s44185-023-00015-5>
- Feltham, H., Park K., Minderman J. and Goulson D. (2015). Experimental evidence that wildflower strips increase pollinator visits to crops. *Ecol. Evol.*, **5**(16), 3523–3530.
- Galante, E. and Marcos-Garcia M.A. (2004). Decomposer Insects. In: *Encyclopedia of Entomology*. Springer, Dordrecht.
- IPBES (2016). The assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. Potts, S.G., Imperatriz-Fonseca V.L. and Ngo H.T. (eds). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. 552 pages.
- Klein, A.M., Vaissière B.E., Cane J.H., Steffan-Dewenter I., Cunningham S.A., Kremen C. and Tscharntke T. (2007). Importance of pollinators in changing landscapes for world crops. *Proc Biol Sci.*, **274**(1608), 303–313.
- Maccagnani, B. and Sgolastra F. (2020). Solitary Bees as Pollinators. In: Smagghe, G., Boecking O., Maccagnani B., Mänd M. and Kevan P. (eds) *Entomovectoring for Precision Biocontrol and Enhanced Pollination of Crops*. Springer, Cham.
- MacIvor, J.S. and Packer L. (2015). Bee Hotels' as Tools for Native Pollinator Conservation: A Premature Verdict? *PLoS ONE*, **10**(3), e0122126.
- Mukhtar, Y., Shankar U. and Wazir Z.A. (2023). Wild bee pollinators and their role in pollination. *Int. J. Agricult. Sci.*, **8**, 92–96.
- Neumann, A.E., Conitz F.E., Karleowski S., Sturm U., Schmack J.M. and Egerer M. (2024). Flower richness is key to pollinator abundance: The role of garden features in cities. *Basic Appl. Ecol.*, **79**, 102–113.
- Öckinger, E. and Smith H.G. (2007). Asymmetric dispersal and survival indicate population sources for grassland butterflies in agricultural landscapes. *Ecography*, **30**(2), 288–298.
- Opdam, P. and Wascher D. (2004). Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. *Biological Conservation*, **117**(3), 285–297.
- Potts, S.G., Biesmeijer J.C., Kremen C., Neumann P., Schweiger O. and Kunin W.E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends Ecol Evol.*, **25**(6), 345–353.
- Rahimi, E., Barghjelveh S. and Dong P. (2021). How effective are artificial nests in attracting bees? A review. *J. Ecol. Environ.*, **45**, 16.
- Seibold, S., Rammer W., Hothorn T. *et al.* (2021). The contribution of insects to global forest deadwood decomposition. *Nature*, **597**, 77–81.
- Tuell, J.K., Fiedler A.K., Landis D. and Isaacs R. (2008). Visitation by wild and managed bees (Hymenoptera: Apoidea) to eastern US native plants for use in conservation programs. *Environ Entomol.*, **37**(3), 707–718.
- Ulyshen, M.D. (2016). Wood decomposition as influenced by invertebrates. *Biol Rev.*, **91**(1), 70–85.
- Verma, R.C., Waseem M.A., Sharma N., Bharathi K., Singh S., Rashwin A.A., Pandey S.K. and Singh B.V. (2023). The Role of Insects in Ecosystems: An in-depth Review of Entomological Research. *Int. J. Environ. Clim. Change*, **13**(10), 4340–4348.
- Yang, L.H. and Gratton C. (2014). Insects as drivers of ecosystem processes. *Curr. Opin. Insect Sci.*, **2**, 26–32.