PLANT SCIENCE TODAY
Vol 13(sp1): 01–06
https://doi.org/10.14719/pst.10520

eISSN 2348-1900

RESEARCH ARTICLE

Restoring insect diversity enhances biodegradation and pollination services in forest ecosystems

R K Gupta[1], Kamlesh Bali[2] & Ranjana Bali[2*]

[1]Division of Entomology, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha, Jammu & Kashmir 180 009, India
[2]Division of Sericulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha, Jammu & Kashmir 180 009, India

*Correspondence email - baliranjana3@gmail.com

Received: 08 July 2025; Accepted: 14 October 2025; Available online: Version 1.0: 15 January 2026

Cite this article: Gupta RK, Kamlesh B, Ranjana B. Restoring insect diversity enhances biodegradation and pollination services in forest ecosystems. Plant Science Today. 2026;13(sp1):01–06. https://doi.org/10.14719/pst.10520

Abstract

Insects play a pivotal role in ecosystem functioning by mediating essential services such as biodegradation and pollination. This study, conducted over two years (2023 and 2024), assessed the impact of insect diversity restoration on biodegradation and pollination in a protected forest. Data collected before and after restoration indicated a significant increase in insect-mediated ecosystem services. The abundance of decomposer insects like Collembolans increased from 5.02 % to 7.50 %, while wood-decomposing beetles rose by 15.16 % and 23.00 %. The key pollinators such as *Bombus* spp. (bumble bees) and honey bees showed notable improvements in activity on crops. These findings highlight the necessity of conserving insect diversity for ecosystem balance and productivity. Restoration strategies including habitat preservation and eco-friendly practices are vital.

Keywords: biodegradation; conservation; ecosystem services; pollination; protected forest

Introduction

Insects are integral to ecosystem functioning, playing key roles in decomposition, nutrient cycling, pollination and overall biodiversity maintenance (1). Their contribution to essential ecological services such as biodegradation (2) and pollination (3) directly influences soil health, plant productivity and agricultural sustainability. Decomposer insects are crucial for breaking down complex organic matter, thereby facilitating nutrient availability for plant uptake. Collembolans (springtails), isopterans (termites) and coleopterans (wood-decomposing beetles) are among the most efficient decomposers, with their activities directly influencing soil fertility, carbon sequestration and microbial community dynamics (4, 5). Springtails fragment organic material and stimulate microbial activity through the consumption of fungi and bacteria, increasing soil organic matter decomposition, as studied in temperate forests (6).Termites contribute substantially to lignocellulose degradation, breaking down plant material and improving soil aeration (7). Wood-decomposing beetles accelerate recycling of forest biomass (8). The decline of decomposers due to deforestation and land-use change causes slower decomposition and reduced fertility, demonstrating the urgency for effective restoration efforts (9). Insect pollinators facilitate the reproduction of nearly 75 % of all flowering plants and 35 % of global food crops (10). Bees, butterflies, beetles and flies ensure plant community resilience and food security. However, habitat loss, pesticide use and declines in ecosystem functioning underscore the significance of conservation action (11). Honeybees (*Apis* spp.), bumble bees (*Bombus* spp.) and solitary bees collectively ensure high crop yields and genetic diversity, with native species often outperforming managed bees in specialized contexts (12). The conservation of diverse pollinators has also been linked to increased resilience against climate variability, as different species exhibit varying foraging behaviors and environmental tolerances, ensuring stable pollination services throughout changing seasonal conditions (13). In recent decades, the rapid decline in insect populations due to anthropogenic activities, habitat fragmentation, climate change and chemical pesticide use has raised serious ecological concerns (14). Declining decomposer insects reduce the efficiency of organic matter breakdown, leading to the accumulation of undecomposed plant material, slower nutrient recycling and imbalanced soil microbial communities (10). In response to these challenges, conservation strategies focused on restoring insect diversity have gained increasing attention. Few studies have quantified simultaneous, post-restoration improvements in both biodegradation and pollination within protected forests. This gap is addressed here. This study aims to assess the impact of restoring insect diversity on biodegradation and pollination in a protected forest area. We hypothesize that targeted restoration of insect biodiversity will increase the abundance of key decomposers and pollinators, simultaneously enhancing both ecosystem services.

Materials and Methods

Study site and experimental design

The study was conducted during 2023 and 2024 in the forest ecosystems of Jammu, India, encompassing natural forest stands, agroforestry patches and riparian corridors. A before-after restoration framework was adopted: baseline data on insect diversity and ecosystem service metrics were collected prior to interventions, followed by post-restoration assessments after habitat preservation, enrichment planting of native flora and installation of artificial nesting sites.

Insect sampling

Decomposer insects were sampled through pitfall trapping, litter extraction (Berlese–Tullgren funnels) and hand collection. Pollination services were assessed by standardized floral visitation observations on fruit and nut orchards adjacent to the forest ecosystem.

Identification and specimen handling

Insects were identified to the lowest feasible taxonomic level using standard morphological keys (15). Voucher specimens were preserved in 70 % ethanol and curated at the Sher-e-Kashmir University of Agricultural Sciences and Technology (SKUAST-Jammu).

Ecosystem service metrics and data analysis

Decomposition services were inferred from the abundance of Collembola, Isoptera and Coleoptera across habitat types, while pollination services were quantified from visitation rates (visits flower $^{-1}$ min^{-1}) on selected crop species (pear, peach, plum, cherry, pecan, almond, walnut). Pre- and post-restoration changes were tested statistically.

The detailed technical specifications of sampling tools, trap dimensions, ethanol concentration, quadrat layout, funnel setup, observation schedule and statistical models are provided in Supplementary Appendix S1.

Results

Impact on biodegradation services

The restoration of insect diversity significantly enhanced the abundance of decomposer insects, thereby improving biodegradation services. Collembolan species (*Cyphoderus* sp., *Entomobrya* sp., *Isotoma* sp., *Hypogastrura* sp. and *Folsomia* sp.) increased in abundance from 5.02 % in 2023 to 22.50 % in 2024 (Table 1, Fig. 1), highlighting their role in fragmenting plant material and facilitating microbial colonization. Wood-decomposing beetles (*Anoplophora glabripennis*, *Stictoleptura rubra*, *Arhopalus rusticus* and *Chalcophora mariana*) showed a notable rise from 15.16 % to 23.0 %, suggesting that habitat preservation and artificial deadwood placements supported the resurgence of saproxylic beetles. Termites (*Odontotermes obesus, Macrotermes obesi, Nasutitermes jaraguae, Macrotermes natalensis, Macrotermes subhyalinus* and *Macrotermes bellicosus*) exhibited the highest increase, rising from 21.45 % to 30.0 %, while proturans also increased from 9.54 % to 16.30 % post-restoration. These changes indicate that restoration interventions effectively enhanced decomposer populations, thereby promoting organic matter turnover and soil enrichment.

Temporal biodiversity recovery patterns

Analysis of temporal changes in insect community structure revealed substantial improvements in overall biodiversity following restoration interventions (Fig. 2). Shannon diversity indices demonstrated consistent elevation across all months in the post-restoration period (2024) compared to baseline conditions (2023), with values ranging from 2.8-4.2 versus 2.0-3.1 respectively. Peak diversity occurred during spring and early summer months (April-June), reaching maximum values of 4.2 in May 2024 compared to 3.1 in May 2023, representing a 35 % increase in community diversity. Notably, even winter months (December-February) maintained higher diversity indices (2.8-3.1) in the post-restoration period compared to the same months in the pre-restoration year (2.0-2.2). This sustained elevation of diversity indices throughout seasonal fluctuations indicates that restoration interventions provided year-round habitat stability and resource availability, supporting resilient insect communities even during challenging environmental conditions.

Enhancement of pollination services

Pollinator activity increased across all observed horticultural crops following restoration, particularly in pears, cherries and almonds (Table 2, Fig. 3). Foraging by key pollinators including *Bombus* spp., *Apis mellifera* (European honeybee), *Apis cerana* (Asiatic honeybee), *Andrena* spp. (digger bees) and *Osmia* sp. (mason bees) showed marked improvement reflecting enhanced pollination efficiency. Nut crops such as pecan, almond and walnut also demonstrated pronounced increases in visitation rates, confirming that restoration of insect diversity positively influenced pollination services and supports agricultural productivity and ecosystem resilience.

Statistical robustness

Changes in decomposer and pollinator groups were statistically significant ($p < 0.05$). Standard deviations or standard errors (SD/SE) are provided in Table 1 and 2 and figures include legends explaining abbreviations and insect groups.

Table 1. Biodegradation services mediated by insects before and after restoration

Order	Ecosystem service description	Restoration	Services contribution (%)
Collembola	Feed on dead organic matter and plant-parasitic microorganisms; enhance mycorrhizae growth	Before	5.02 ± 0.40[a]
		After	22.50 ± 0.11[b]
Coleoptera	Decompose undecayed wood	Before	15.16 ± 0.70[a]
		After	28.00 ± 1.09[b]
Isoptera	Decompose wood and plant organic matter	Before	21.45 ± 0.47[a]
		After	37.00 ± 0.17[b]
Proturans	Feed on decaying plant material; specialized mycorrhizal feeders	Before	9.54 ± 1.03[a]
		After	19.30 ± 0.52[b]

[*]Data are expressed as mean ± SE of five replications. Within a column, mean with different superscripts differ significantly by Tukey's HSD test ($p < 0.05$).

Table 2. Restoration-induced shifts in insect pollinator assemblages of horticultural crops

Crop	Beneficial insect	Restoration	Foraging rate (%)
Pear	*Bombus* spp., *A. mellifera*, *A. cerana*	Before	56.21 ± 0.67^{a}
		After	70.10 ± 1.15^{b}
Peach	*Bombus* spp., *Andrena* spp.	Before	42.00 ± 1.15^{a}
		After	62.10 ± 1.42^{b}
Plum	*A. mellifera*, *A. cerana*	Before	49.23 ± 0.98^{a}
		After	65.05 ± 0.62^{b}
Cherry	*A. mellifera*, *A. Cerana, Osmia* sp.	Before	64.04 ± 1.05^{a}
		After	84.41 ± 0.82^{b}
Peanut	*A. mellifera*, *A. cerana*	Before	9.19 ± 0.50^{a}
		After	19.23 ± 1.07^{b}
Almond	*A. mellifera*, *A. cerana*	Before	68.12 ± 1.48^{a}
		After	29.80 ± 0.63^{b}
Walnuts	*A. mellifera*, *A. cerana*	Before	10.24 ± 0.79^{a}
		After	87.00 ± 1.15^{b}

*Data are expressed as mean ± SE of five replications. within a column, means with different superscripts differ significantly by Tukey's HSD test ($p < 0.05$).

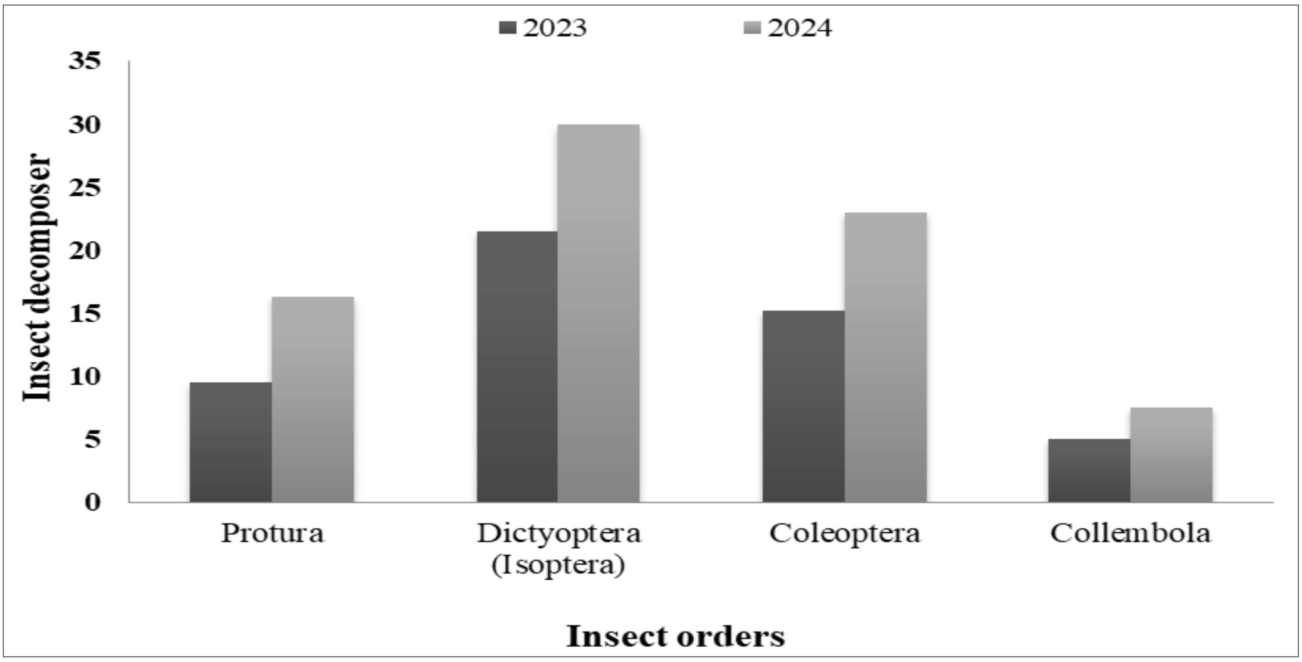

Fig. 1. Interannual variation in decomposer insect abundance (%) during 2023–2024.

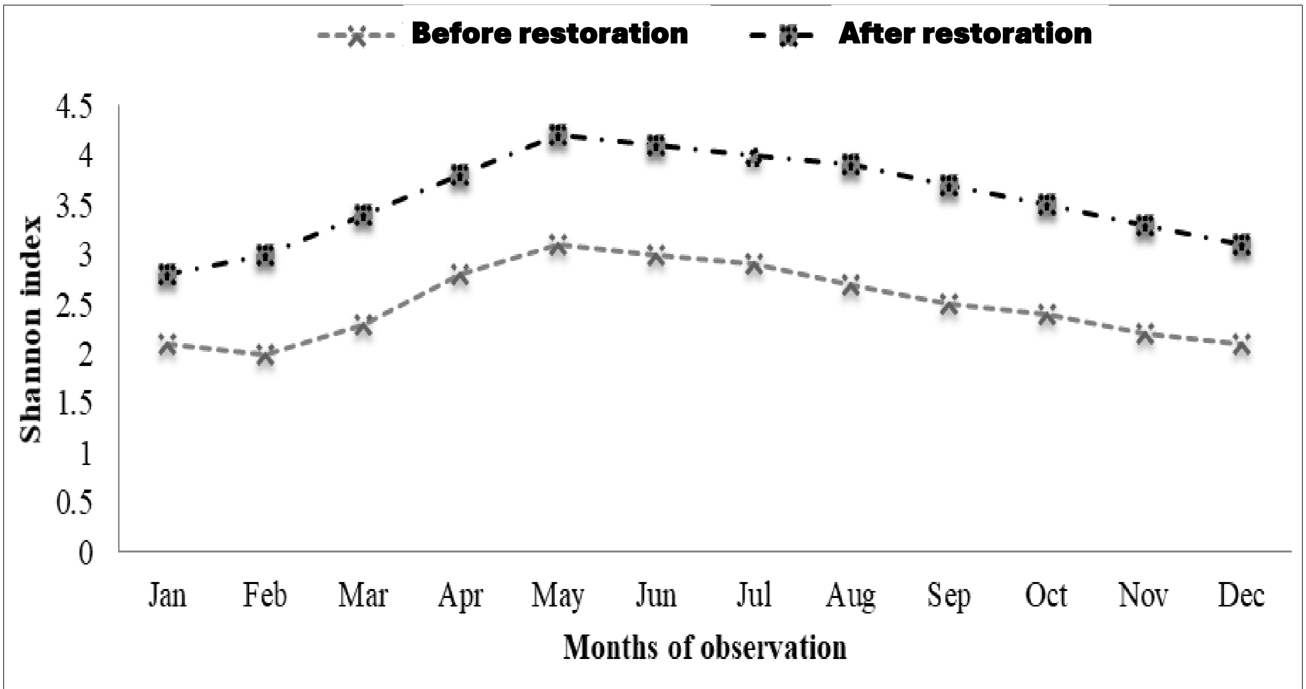

Fig. 2. Insect biodiversity recovery following forest restoration based on the Shannon index.

("Before Restoration" and "After Restoration" indicates Shannon index values measured before and after the implementation of restoration measures respectively).

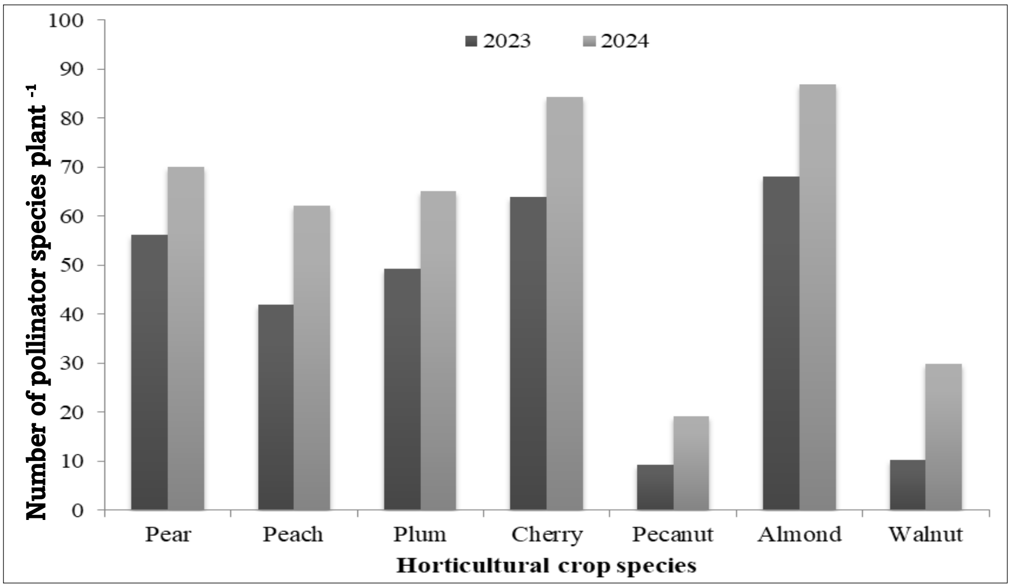

Fig. 3. Pollinator species frequency observed on horticultural crops.

Discussion

Ecological implications of restoration

The restoration of insect diversity in the protected forest area significantly enhanced both biodegradation and pollination services, demonstrating the effectiveness of habitat conservation strategies in supporting insect-mediated ecosystem functions (15, 16). Increases in decomposer populations, particularly collembolans, termites and wood-decomposing beetles indicate that restoration interventions promoted soil microfauna activity, accelerating organic matter decomposition, enhancing microbial colonization and improving nutrient cycling. Collembolans serve as key soil health indicators, highlighting improved fragmentation of plant material and facilitation of microbial processes (6). Termites contribute substantially to lignocellulosic breakdown, carbon turnover and soil aeration, reinforcing the role of decomposers in maintaining soil fertility and ecosystem stability (17, 18). Wood-decomposing beetles create microhabitats for fungi and detritivores, further supporting efficient nutrient cycling and carbon processing (8, 19–21). Pollinator populations increased across all horticultural crops, particularly pears, cherries and almonds, demonstrating the ecological importance of diverse insect communities for agricultural productivity. Complementary foraging behaviors of key pollinators, including *Bombus* spp.*, A. mellifera, A. cerana, Andrena* spp. *and Osmia* sp., enhanced overall pollination efficiency, contributing to improved fruit set, seed viability and yield optimization (10, 12, 22-27). Restoration interventions such as floral resource enrichment, habitat protection and artificial nesting sites likely facilitated these improvements by providing better foraging and nesting resources. The temporal analysis of Shannon diversity indices further supports these findings, showing that restoration created stable, year-round habitat conditions that sustained diverse insect communities across seasonal variations.

Linkage to broader ecosystem services

These findings illustrate that insect-mediated processes underpin soil fertility, nutrient and carbon cycling and food security. Enhancing decomposer and pollinator diversity not only improves ecosystem resilience but also supports the productivity of surrounding agricultural landscapes, highlighting the broader ecological and socioeconomic benefits of conservation efforts. The sustained biodiversity improvements observed throughout the study period indicate that restoration interventions created self-reinforcing positive feedback loops, where enhanced habitat quality supported greater insect diversity, which in turn improved ecosystem service delivery.

Future research directions

Future studies should include long-term monitoring and conservation of insect diversity and their ecosystem service contributions. Molecular studies of soil microbes could elucidate decomposition mechanisms, while landscape-scale investigations would help clarify pollinator movement and habitat connectivity. Assessing the effects of climate variability on both decomposer and pollinator communities is also critical for predicting ecosystem resilience under changing environmental conditions. Additionally, investigating the specific mechanisms underlying seasonal diversity patterns could inform more targeted restoration strategies.

Practical recommendations for forest managers

Forest management should prioritize habitat enrichment, minimize pesticide use, promote native vegetation and establish artificial nesting sites. Integrating diversified cropping systems with restored forest patches can enhance insect-mediated services, thereby supporting both ecological sustainability and agricultural productivity. Such interventions are likely to enhance long-term ecosystem stability and resilience in the face of environmental change (23). Forest managers should plan interventions according to seasonal insect activity patterns to maximize their effectiveness.

Conclusion

Restoring insect diversity significantly enhanced biodegradation and pollination services, accelerating organic matter decomposition, improving soil health and boosting crop productivity. The increased abundance of decomposers facilitated nutrient cycling, while higher pollinator activity improved fruit set and overall crop yield. Temporal analysis revealed sustained improvements in community diversity across seasonal variations, indicating the creation of stable, year-round habitat conditions. These results demonstrate that habitat restoration and conservation strategies are effective tools for sustaining vital ecosystem functions. For practical application, forest managers should prioritize habitat enrichment, promoting native vegetation, establishing artificial nesting sites and reducing pesticide use to maintain diverse insect communities. Integrating restored forest patches with agro-ecosystems can enhance pollinator visitation and nutrient cycling, contributing to long-term ecological resilience and sustainable forest and agricultural management. Overall, this study underscores the importance of insect diversity for ecosystem stability, food security and the resilience of forest-agriculture interfaces, providing actionable insights for policy, forestry practices and agro-ecosystem management.

Acknowledgements

The authors express their sincere gratitude to the Department of Biotechnology (DBT) for providing the necessary funds and support to carry out this research. We are grateful to the Department for approving and guiding this project under its esteemed programs. We also extend our heartfelt thanks to our host institute, SKUAST-JAMMU, Chatha, for providing the infrastructure, laboratory facilities and a conducive environment for the successful execution of this work. The encouragement and assistance of all colleagues and staff involved in this project are deeply appreciated.

Authors' contributions

RKG contributed in its conceptualization, design and provide guidance during the study. KB contributed to provide the resources, designing methodology, curate the data and supervised the study. RB drafted the manuscript, conducted experiments, data collection and statistical analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Verma RC, Waseem MA, Sharma N, Bharathi K, Singh S, Rashwin AA, et al. The role of insects in ecosystems: An in-depth review of entomological research. Int J Environ Clim Change. 2023;13(10):4340–48. https://doi.org/10.9734/ijecc/2023/v13i103110
2. Adhikari P, Aryal N, Ghimire A, Khanal P. Sustainable bio-waste recycling using insects. In: Tyagi V, Aboudi K, editors. Clean energy and resources recovery. Elsevier; 2021. p. 399–420. https://doi.org/10.1016/B978-0-323-85223-4.00007-5
3. Kumar G, Khan MS. Insects as crop pollinators. In: Omkar, editor. Insects as service providers. Singapore: Springer; 2023. pp. 37-64. https://doi.org/10.1007/978-981-19-3406-3_3
4. Bignell DE, Eggleton P. Termites in ecosystems. In: Abe T, Bignell DE, Higashi M, editors. Termites: evolution, sociality, symbioses, ecology. Dordrecht: Springer; 2000. https://doi.org/10.1007/978-94-017-3223-9_17
5. Galante E, Marcos-Garcia MA. Decomposer insects. In: Capinera JL, editor. Encyclopedia of entomology. Dordrecht: Springer; 2008.
6. Bardgett RD, van der Putten WH. Belowground biodiversity and ecosystem functioning. Nature. 2014;515:505–11. https://doi.org/10.1038/nature13855
7. Talia P, Arneodo J. Lignocellulose degradation by termites. In: Khan M, Ahmad W, editors. Termites and sustainable management. Sustainability in plant and crop protection. Springer; 2018. p. 101–17. https://doi.org/10.1007/978-3-319-72110-1_5
8. Skelton J, Jusino MA, Carlson PS, Smith K, Banik MT, Lindner DL, et al. Relationships among wood-boring beetles, fungi and the decomposition of forest biomass. Mol Ecol. 2019;28(22):4971–86. https://doi.org/10.1111/mec.15263
9. New TR. Consequences of insect declines and loss. In: Insect conservation in Australia: why and how. Cham: Springer; 2024. p. 69–80. https://doi.org/10.1007/978-3-031-66631-5
10. Klein AM, Vaissiere BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, et al. Importance of pollinators in changing landscapes for world crops. Proc R Soc B. 2007;274(1608):303–13. https://doi.org/10.1098/rspb.2006.3721
11. Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O, Kunin WE. Global pollinator declines: trends, impacts and drivers. Trends Ecol Evol. 2010;25(6):345–53. https://doi.org/10.1016/j.tree.2010.01.007
12. Garibaldi LA, Steffan-Dewenter I, Winfree R, Aizen MA, Bommarco R, Cunningham SA, et al. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. Science. 2013;339(6127):1608–11. https://doi.org/10.1126/science.1230200
13. Katumo DM, Liang H, Ochola AC, Lv M, Wang QF, Yang CF. Pollinator diversity benefits natural and agricultural ecosystems, environmental health and human welfare. Plant Divers. 2022;44(5):429–35. https://doi.org/10.1016/j.pld.2022.01.005
14. Halsch CA, Shapiro AM, Fordyce JA, Nice CC, Thorne JH, Waetjen DP, et al. Insects and recent climate change. Proc Natl Acad Sci U S A. 2021;118(2):e2002543117. https://doi.org/10.1073/pnas.2002543117
15. Upreti G. Importance of biodiversity, ecosystems and ecosystem services. In: Ecosociocentrism. Cham: Springer. 2023. p. 15-30. https://doi.org/10.1007/978-3-031-41754-2_2
16. Vishwapriya C, Devaiah NG. Conservation priorities for Indian biodiversity: spatiotemporal patterns, policy and outlook. Biodivers Conserv. 2024;33:3743–65. https://doi.org/10.1007/s10531-024-02924-8
17. Santhosh KS, Gomathi V, Anandham R, Meenakshisundaram P, Kavitha MJ. Evaluating lignocellulosic enzyme activity of termite mound soil from different locations of Tamil Nadu. J Pharmacogn Phytochem. 2020;9(6):762–64. https://doi.org/10.22271/phyto.2020.v9.i6k.13034
18. Sugimoto A, Bignell DE, MacDonald JA. Global impact of termites on the carbon cycle and atmospheric trace gases. In: Abe T, Bignell DE, Higashi M, editors. Termites: evolution, sociality, symbioses, ecology. Dordrecht: Springer. 2000. pp 409–35. https://doi.org/10.1007/978-94-017-3223-9_19
19. Uma GS, Sharma L, Rathna V. The Role of insects in nutrient cycling: unsung heroes of ecosystem health. Vigyan Varta. 2023;4(9):40–42.
20. Weiss M, Didham RK, Procházka J, Schlaghamerský J, Basset Y, Odegaard F, et al. Saproxylic beetles in tropical and temperate forests – a standardized comparison of vertical stratification patterns. 2019;444:50–8. https://doi.org/10.1016/j.foreco.2019.04.021
21. Zumr V, Nakladal O, Gallo J, Remeš J. Deadwood position matters: Diversity and biomass of saproxylic beetles in a temperate beech forest. For Ecosyst. 2024;11:100174. https://doi.org/10.1016/j.fecs.2024.100174
22. Parrey HA, Raina HR, Saddam B, Pathak P, Kumar S, Uniyal VP, et al. Role of bumblebees (Hymenoptera: Apidae) in pollination of high land ecosystems: A review. Agric Rev. 2022;43(3):368–73.
23. Nayak RK, Rana K, Bairwa VK, Singh P, Bharthi VD. A review on role of bumblebee pollination in fruits and vegetables. J Pharmacogn Phytochem. 2020;9(3):1328–34. https://doi.org/10.22271/phyto.2020.v9.i3v.11494

24. Osterman J, Benton F, Hellström S, Luderer-Pflimpfl M, Pöpel-Eisenbrandt AK, Wild BS, et al. Mason bees and honey bees synergistically enhance fruit set in sweet cherry orchards. Ecol Evol. 2023;13(7):e10289.

25. Bosch J, Kemp WP. How to manage the blue orchard bee as an orchard pollinator. Beltsville (MD): Sustainable Agriculture Network. 2001.

26. Albrecht M, Schmid B, Hautier Y, Müller CB. Diverse pollinator communities enhance plant reproductive success. Proc R Soc B. 2012;279(1748):4845–52. https://doi.org/10.1098/rspb.2012.1621

27. Saez A, Arbona G, Juan A, Ferragut BC, Anna T. Pollinators' contribution to seed yield in two self-fertile almond varieties role of bees for self-fertile almonds. Apidologie. 2024;55:19. https://doi.org/10.1007/s13592-024-01064-w

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.