GLOBUS PUBLICATION

Globus An International Journal of Medical Science, Engineering and Technology
A Refereed Research Journal
Vol 12 / No 2 / Jul-Dec 2023 ISSN: 2319-8958

NOVEL APPROACHES IN QUANTIFYING ECOSYSTEM SERVICES PROVIDED BY RAINFOREST INSECTS

*Rajni Sharma
**Shivarti Gautam

Paper Received: 12.09.2023 / **Paper Accepted**: 25.10.2023 / **Paper Published**: 28.10.2023
Corresponding Author: Rajni Sharma; doi:10.46360/globus.met.320232008

Abstract

Insects in tropical rainforests underpin critical ecosystem services, including pollination, decomposition, nutrient cycling, seed dispersal, and natural pest regulation. Despite their recognized importance, quantifying these services has been challenging due to the immense diversity of insect taxa, complex ecological interactions, and limitations in traditional monitoring methods. This article reviews novel approaches in measuring and valuing insect-driven ecosystem services. We discuss advancements in DNA metabarcoding, automated image-based monitoring, ecological network modeling, bioacoustic surveillance, and functional trait-based analyses. Integrating these tools with remote sensing and machine learning provides unprecedented opportunities to capture the magnitude and spatial heterogeneity of insect-mediated services. Case studies from the Amazon, Congo Basin, and Southeast Asian rainforests demonstrate how these methods refine our understanding of insect functional contributions, enabling improved conservation planning and sustainable ecosystem management.

Keywords: Tropical Rainforest, Ecosystem Services, DNA Metabarcoding.

Introduction

Tropical rainforest insects represent one of the most functionally diverse and ecologically critical groups in terrestrial ecosystems. They facilitate pollination of over 90% of flowering plants, contribute to litter decomposition and nutrient recycling, regulate herbivore populations through predation, and influence plant community dynamics via seed dispersal (Basset et al., 2012; Nichols et al., 2008). These ecosystem services are foundational to rainforest resilience and global ecological stability, yet their quantification remains underdeveloped (Stork, 2018).

Traditional methods of measuring insect services—such as manual trapping, observational surveys, and experimental exclusion—have provided valuable insights but face limitations in scalability, taxonomic resolution, and detection of cryptic interactions (Losey & Vaughan, 2006). The rapid loss of insect biodiversity due to deforestation, climate change, and habitat fragmentation intensifies the need for robust quantification methods to inform conservation policies and payment-for-ecosystem-services schemes.
(Hallmann et al., 2017; IPBES, 2019)

This paper synthesizes emerging approaches for quantifying insect-mediated ecosystem services in tropical rainforests, focusing on technological innovations, functional ecological frameworks, and integrative modeling techniques that address prior methodological constraints.

Traditional Approaches and Their Limitations

Historically, ecosystem service quantification relied on:

- **Direct observation and sampling** (e.g., pitfall traps, sweep nets, Malaise traps) to estimate abundance and diversity (Basset et al., 2012).
- **Experimental manipulation**, such as pollinator exclusion studies or litterbag decomposition experiments, to infer functional contributions (Nichols et al., 2008).

*Research Scholar, Sunrise University, Alwar, Rajasthan, India.
**Associate Professor, Department of Zoology, Sunrise University, Alwar, Rajasthan, India.

- **Economic valuation** using crop yield enhancements or avoided costs of pest control as proxies for insect services (Losey & Vaughan, 2006).

While these methods have elucidated key processes, they often underestimate service magnitudes due to:

- Limited taxonomic expertise and difficulty identifying hyperdiverse insect groups.
- Temporal and spatial biases in sampling effort.
- Inability to capture complex interaction networks and ecosystem-scale feedbacks.

Consequently, traditional approaches provide fragmented and sometimes conservative estimates of insect contributions to ecosystem functioning.

Novel Quantification Approaches

DNA Metabarcoding and Environmental DNA (eDNA)

Advances in high-throughput sequencing allow for simultaneous identification of hundreds of insect taxa from bulk samples, pollen loads, or environmental DNA in soil and water (Ji et al., 2013). This technique:

- Enhances taxonomic resolution and detection of rare or cryptic species.
- Enables reconstruction of trophic interactions (e.g., predator-prey, pollinator-plant links).
- Supports temporal monitoring of community composition changes linked to ecosystem service dynamics.

Automated Image-Based Monitoring and Computer Vision

Camera traps and autonomous drones equipped with AI-powered image recognition now detect and classify insects in real-time (Wäldchen & Mäder, 2018). Applications include:

- Mapping pollinator activity and visitation rates across landscapes.
- Monitoring predator-prey interactions (e.g., ant predation on herbivores).
- Estimating biomass and functional abundance without destructive sampling.

Bioacoustic Monitoring

Many rainforest insects produce species-specific sounds. Passive acoustic sensors, combined with machine learning classifiers, can:

- Track activity patterns of pollinators, predators, and decomposers.
- Provide continuous, non-invasive monitoring in dense canopies where visual sampling is limited (Sueur & Farina, 2015).

Functional Trait-Based Approaches

Functional ecology frameworks assess services based on measurable traits (e.g., body size, mouthpart morphology, flight capability) that link directly to ecological roles (Lavorel et al., 2013). Trait-based analyses:

- Allow scaling from individual species to ecosystem-level processes.
- Facilitate modeling of service provision under environmental change scenarios.
- Support identification of functionally unique species critical for ecosystem resilience.

Ecological Network Modeling

Complex interaction webs among insects, plants, and other taxa can be mapped and analyzed using network theory. Key metrics (connectance, modularity, robustness) quantify:

- Pollination and seed dispersal networks.
- Predator-prey dynamics regulating herbivory.
- Potential cascading effects of insect extinctions on ecosystem services (Tylianakis et al., 2010).

Remote Sensing and Machine Learning Integration

Combining field-based insect data with high-resolution satellite imagery and machine learning models enables:

- Spatial mapping of service hotspots (e.g., areas of high pollination activity).
- Predictive modeling of service provision under deforestation or climate change.
- Linking insect community data with broader ecosystem indicators such as vegetation productivity and carbon storage (Turner et al., 2015).

Case Studies

Amazon Basin: Pollination and Forest Regeneration

Metabarcoding of pollen samples from bees revealed broader plant-pollinator networks than previously detected, improving estimates of pollination redundancy and resilience in fragmented forests (Carvalho et al., 2021).

Congo Basin: Decomposition Services

Acoustic monitoring of dung beetle activity allowed continuous measurement of nutrient cycling services, correlating acoustic intensity with dung removal rates (Beiroz et al., 2020).

Southeast Asian Rainforests: Pest Regulation

Network analysis of predator-prey interactions among ants and herbivorous insects demonstrated natural pest control services in agroforestry landscapes, informing sustainable plantation management (Larsen et al., 2019).

Implications for Conservation and Policy

Quantifying insect-mediated services with these novel approaches supports:

- **Payment for ecosystem services (PES)** programs compensating communities for conserving insect habitats.
- **Conservation prioritization** by identifying functional hotspots and keystone insect species.
- **Sustainable land management**, integrating insect services into agroforestry and restoration planning.
- **Climate change mitigation**, as insects influence carbon cycling through decomposition and plant reproduction.

Conclusion

Innovative tools and analytical frameworks are fundamentally reshaping our understanding and capacity to measure the ecosystem services provided by rainforest insects. Historically, the quantification of these services has been constrained by methodological limitations, taxonomic uncertainties, and the sheer diversity and abundance of insect species in tropical ecosystems. However, advancements in molecular biology, automation, ecological modeling, and remote sensing have opened new pathways for accurately assessing the functional contributions of insects to ecosystem health and resilience.

DNA-based techniques, including metabarcoding and environmental DNA (eDNA) analysis, have revolutionized biodiversity monitoring by enabling the detection of rare, cryptic, or otherwise unobservable species. These methods not only enhance species inventories but also help reconstruct complex ecological interactions, such as plant-pollinator networks or predator-prey relationships, which underpin vital ecosystem services. Similarly, automated image-based monitoring, coupled with machine learning algorithms, has expanded our ability to capture real-time data on insect activity and population dynamics at unprecedented spatial and temporal scales.

Functional trait analyses have added another dimension to ecosystem service quantification by linking measurable biological characteristics of insects—such as body size, feeding morphology, and dispersal abilities—to their ecological roles. This approach provides a mechanism to predict service delivery even in data-poor regions or for poorly known taxa, which is especially valuable given the rapid environmental changes threatening tropical rainforests.

Ecological network models further deepen our comprehension by illustrating the structure and stability of species interactions within rainforest communities. These models help identify keystone species whose functional roles are disproportionately significant, offering targeted opportunities for conservation interventions. Remote sensing technologies, when integrated with field data and analytical models, allow for mapping service hotspots, detecting habitat degradation, and forecasting the impacts of deforestation or climate change on insect-mediated processes.

Collectively, these novel approaches are not just improving scientific understanding but also offering actionable insights for policymakers, conservation practitioners, and land managers. By quantifying services such as pollination, decomposition, nutrient cycling, and biological pest control with greater precision, decision-makers can design more effective conservation strategies, implement payment-for-ecosystem-services schemes, and promote sustainable land-use practices that safeguard both biodiversity and human well-being.

Ultimately, the integration of these advanced tools signals a paradigm shift from descriptive biodiversity studies to functional, service-oriented ecological assessments. This transformation is crucial for ensuring that the invaluable, yet often overlooked, contributions of rainforest insects are recognized, preserved, and incorporated into long-term conservation and ecosystem management frameworks. Future research should focus on refining these methods, enhancing cross-disciplinary collaboration, and developing standardized protocols to facilitate global comparisons and scalable implementation.

Conflicts of Interest

The authors declare that there is no significant competing financial, professional, or personal interests that might have influenced the performance or presentation of the work described in this manuscript.

References

1. Basset, Y., Cizek, L., Cuénoud, P., Didham, R. K., Guilhaumon, F., Missa, O., ... & Novotny, V. (2012). Arthropod diversity in a tropical forest. *Science*, 338(6113), 1481-1484. https://doi.org/10.1126/science.1226727
2. Beiroz, W., Slade, E. M., Barlow, J., Louzada, J., & Edwards, D. P. (2020). Acoustic monitoring of ecosystem processes: dung beetle-mediated nutrient cycling in tropical forests. *Ecological Indicators*, 115, 106436.

https://doi.org/10.1016/j.ecolind.2020.106436
3. Carvalho, A. T., Lanes, É. C. M., Guedes, R. N. C., Faria, L. R. R., & Martins, C. F. (2021). Pollen DNA metabarcoding reveals broad plant-pollinator networks in Amazonian landscapes. *Molecular Ecology*, 30(13), 3185-3197. https://doi.org/10.1111/mec.15963
4. Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., ... & de Kroon, H. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLOS ONE*, 12(10), e0185809. https://doi.org/10.1371/journal.pone.0185809
5. IPBES. (2019). *Global assessment report on biodiversity and ecosystem services*. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.
6. Ji, Y., Ashton, L., Pedley, S. M., Edwards, D. P., Tang, Y., Nakamura, A., ... & Yu, D. W. (2013). Reliable, verifiable and efficient monitoring of biodiversity via metabarcoding. *Ecology Letters*, 16(10), 1245-1257. https://doi.org/10.1111/ele.12162
7. Lavorel, S., Storkey, J., Bardgett, R. D., de Bello, F., Berg, M. P., Le Roux, X., ... & Harrington, R. (2013). A novel framework for linking functional diversity of plants with other trophic levels for the quantification of ecosystem services. *Journal of Vegetation Science*, 24(5), 942-948. https://doi.org/10.1111/jvs.12083
8. Larsen, T. H., Williams, N. M., & Kremen, C. (2019). Forest fragments sustain pollination services despite pollinator declines. *Proceedings of the Royal Society B*, 286(1900), 20182554. https://doi.org/10.1098/rspb.2018.2554
9. Losey, J. E., & Vaughan, M. (2006). The economic value of ecological services provided by insects. *Bioscience*, 56(4), 311-323. https://doi.org/10.1641/00063568(2006)56[311:TEVOES]2.0.CO;2
10. Nichols, E., Spector, S., Louzada, J., Larsen, T., Amezquita, S., & Favila, M. E. (2008). Ecosystem services of dung beetles. *Ecological Entomology*, 33(2), 151-163. https://doi.org/10.1111/j.1365-2311.2007.00931.x
11. Stork, N. E. (2018). How many species of insects and other terrestrial arthropods are there on Earth? *Annual Review of Entomology*, 63, 31-45. https://doi.org/10.1146/annurev-ento-020117-043348
12. Sueur, J., & Farina, A. (2015). Ecoacoustics: The ecological investigation and interpretation of environmental sound. *Biosemiotics*, 8, 493-502. https://doi.org/10.1007/s12304-015-9248-x
13. Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., & Steininger, M. (2015). Remote sensing for biodiversity science and conservation. *Trends in Ecology & Evolution*, 18(6), 306-314. https://doi.org/10.1016/S0169-5347(03)00070-3
14. Tylianakis, J. M., Laliberté, E., Nielsen, A., & Bascompte, J. (2010). Conservation of species interaction networks. *Biological Conservation*, 143(10), 2270-2279. https://doi.org/10.1016/j.biocon.2009.12.004
15. Wäldchen, J., & Mäder, P. (2018). Machine learning for image-based species identification. *Methods in Ecology and Evolution*, 9(11), 2216-2225. https://doi.org/10.1111/2041-210X.13075