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Opinion

Recovery under pressure: Pollinator services and biodiversity trends across restored and human-modified landscapes

Tomas A. Torres*

Department of Wildlife Ecology, University of California, Davis, USA

**Corresponding author E-mail: tatorres@ucvis.edu*

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Pollinators are crucial for ecosystem function, agricultural productivity and biodiversity maintenance, yet they face increasing pressures from habitat loss, land-use change, climate stress and agrochemical exposure. Restoration of degraded landscapes and management of human-modified ecosystems are critical strategies to sustain pollinator services and maintain biodiversity. This article examines the dynamics of pollinator populations and associated biodiversity trends across restored and human-altered landscapes, integrating evidence from field studies, meta-analyses and ecological modeling. It highlights how habitat complexity, floral diversity, connectivity and landscape management practices influence pollinator recovery and ecosystem resilience. The article further explores trade-offs between agricultural intensification and conservation goals, emphasizing strategies that optimize pollination services, biodiversity and ecosystem sustainability. Understanding these trends is vital for informing restoration practices, landscape planning and policy frameworks that support both biodiversity conservation and human well-being under global change.

Keywords: Pollinator services, Biodiversity trends, Landscape restoration, Human-modified landscapes, Ecosystem resilience, Habitat connectivity, Agroecology, Ecosystem services.

Introduction

Pollinators, including bees, butterflies, flies and other insects, are essential components of terrestrial ecosystems. They facilitate reproduction in a wide range of wild plants and crops, supporting food security, genetic diversity and ecosystem resilience. Globally, pollinator populations are experiencing unprecedented declines due to habitat fragmentation, pesticide exposure, invasive species and climate change. These declines threaten ecosystem services and biodiversity, with cascading effects on human well-being and agricultural productivity. Human-modified landscapes, including agricultural fields, urban areas and industrial zones, present both challenges and opportunities for pollinator conservation. Degradation and homogenization of habitats reduce floral diversity and nesting resources, while restored landscapes—through reforestation, grassland recovery and urban greening—can support the recovery of pollinator communities. Understanding pollinator dynamics in these landscapes requires a multiscale perspective that integrates ecological, spatial and socio-economic factors (Kale JR, et al. 2009). This examines the patterns of pollinator recovery and biodiversity trends across restored and human-modified landscapes. It explores the mechanisms driving pollinator population dynamics, the role of habitat management and the implications for ecosystem services and biodiversity conservation under global environmental pressures.

Description

Pollinator populations are declining due to multiple, often interacting pressures. Habitat loss from urbanization and agricultural intensification reduces floral and nesting resources. Pesticide exposure, particularly neonicotinoids, affects pollinator survival, reproduction and behavior. Climate change alters phenology, shifts species distributions and exacerbates drought and heat stress. Invasive species can compete with native pollinators or disrupt plant-pollinator networks. These pressures collectively reduce species richness, abundance and functional diversity, with consequences for ecosystem resilience (Saldiva PH, et al. 1995). Declines in pollinator diversity and abundance reduce pollination services, leading to lower crop yields, reduced genetic diversity of plants and disrupted plant–pollinator interactions. Functional redundancy within pollinator communities can buffer some impacts, but the loss of key species or functional groups can result in abrupt declines in pollination efficiency. Maintaining diverse and resilient pollinator communities is thus essential for ecosystem service provision and long-term landscape sustainability.

Restored landscapes, such as reforested areas, wildflower meadows and urban green spaces, provide floral resources and nesting habitats critical for pollinator recovery. Habitat complexity, including heterogeneity in plant species composition, flower morphology and spatial arrangement, enhances pollinator diversity by supporting species with different foraging preferences and nesting requirements. Long-term restoration projects demonstrate that pollinator richness and abundance increase with structural and floral diversity, especially when native plant species are prioritized. Landscape connectivity plays a crucial role in pollinator movement and gene flow (Dornelas M, et al. 2018). Restored habitat patches that are well-connected to natural or semi-natural areas facilitate recolonization, reduce isolation effects and promote metapopulation stability. Corridors, hedgerows and buffer zones can enhance landscape connectivity, supporting both common and rare pollinator species. Connectivity also improves resilience to environmental fluctuations, enabling pollinator communities to adapt to climate stress or disturbances. Pollinator recovery is often gradual and depends on multiple ecological and management factors. Early-successional species may colonize restored areas quickly, while specialist and long-lived species may take years to establish (van Klink R, et al. 2021). Recovery trajectories are influenced by initial habitat conditions, landscape context and ongoing management practices such as mowing regimes, invasive species control and pesticide reduction. Adaptive management that monitors species responses and adjusts practices accordingly enhances restoration success.

Intensified agriculture reduces habitat heterogeneity and floral resources, negatively affecting pollinator diversity. Monocultures provide short-term resource pulses but insufficient nesting sites and year-round foraging opportunities. Integrating agroecological practices, such as cover crops, flower strips, hedgerows and reduced pesticide use, can mitigate these impacts. Studies show that diversified farmland can sustain both crop production and pollinator communities, highlighting the potential for reconciling agricultural productivity with conservation goals. Urbanization often fragments natural habitats, but cities can also serve as refuges for pollinators when managed appropriately (Carvalho C, et al. 2022). Urban gardens, green roofs, parks and street plantings provide floral and nesting resources, particularly for generalist pollinators. Pollinator diversity in cities can rival that of agricultural landscapes if habitat heterogeneity and native plant species are incorporated. Urban planning that integrates green infrastructure, community gardens and pollinator-friendly plantings can enhance both biodiversity and human well-being.

Conclusion

Pollinators are essential for ecosystem function, biodiversity and human livelihoods, yet they face mounting pressures from human-modified landscapes and global environmental change. Restoration of degraded habitats and management of agricultural and urban systems can promote pollinator recovery, enhance biodiversity and sustain ecosystem services. Habitat complexity, floral diversity, connectivity and adaptive management are key determinants of recovery trajectories. Understanding pollinator dynamics across restored and human-altered landscapes provides critical insights for biodiversity conservation, sustainable agriculture and ecosystem resilience. Integrated strategies that balance ecological, social and economic objectives are essential to ensure that pollinator services and biodiversity persist under increasing environmental pressures, thereby supporting both natural and human systems in a rapidly changing world.

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Conflict of Interest

The authors declare no conflict of interest.

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