More trees, more moths: how urban treescapes can help reverse moth declines

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Highlights

• Trees are an overlooked tool for improving depleted urban moth communities.

• Trees support many moth species across multiple life stages.

• Evidence from urban areas show benefits of trees for moth diversity.

• Lessons from agri- and forest landscapes inform the use of trees for urban moths.

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Keywords

Lepidoptera; moth conservation; urban ecology; forestry; green infrastructure; habitat connectivity; forest management.

Abstract:

Moths are undergoing widespread declines in abundance, biomass and diversity, with consequences for pollination, herbivory and trophic interactions. Yet moth conservation remains poorly integrated into biodiversity policy and practice, particularly in urban environments. Here, we argue that trees offer an underused, but very timely, opportunity to support urban moth communities. Trees provide larval hostplants, adult food resources, shelter, microclimatic buffering and connectivity, but their benefits depend on more than canopy cover alone. Evidence for how urban treescapes support moths remains limited. We therefore draw on studies from agricultural and forest landscapes, which show that moth communities depend on tree identity, age, structural complexity, sheltered habitat and landscape connectivity. These insights provide practical guidance for designing and managing urban treescapes for moth biodiversity. As humanity becomes increasingly urban, and climate change and pollution make cities less habitable, tree planting is already being expanded to provide cooling, cleaner air, and improved human wellbeing. Incorporating moth ecology into these existing, human-centred initiatives could deliver meaningful conservation gains without requiring new interventions. Selecting suitable tree species, retaining mature and structurally complex vegetation, protecting sheltered woodland cores and connecting parks, gardens, streets and woodland fragments could transform routine urban greening into a practical response to moth declines. Urban trees should therefore be treated not only as infrastructure for liveable, climate-resilient cities for humans, but also as ecological habitat capable of supporting diverse moth communities under intensifying anthropogenic pressures across multiple stages of their complex life cycles.

Main

Moth declines and overlooked conservation opportunities:

Moths are among the most diverse insect groups and contribute substantially to ecosystem functioning as herbivores, pollinators and prey for many other organisms [1–4]. In urban areas, moths are among the more visible insects, congregating around artificial lights and visiting flowers in gardens and allotments[3,5]. Yet long-term monitoring shows declines in moth abundance, biomass and diversity, alongside substantial reorganisation of communities under land use and climate change [6–8], including in urban areas[9–14].

Despite growing concern over moth declines, this taxon remains underrepresented in conservation prioritisation and practice relative to butterflies and other diurnal pollinators[15]. Interventions designed to support bees and butterflies (e.g. wildflower strips) or broader environmental goals (e.g. pesticide reduction, biological carbon sequestration) may benefit moths[16–18]. However, without integrating the complex habitat and larval hostplant requirements of moths, they may also fail to provide key resources[19,20] or even contribute to declines of specialist species[21]. This has resulted in a persistent evidence gap: moths are often assumed to benefit from ongoing conservation interventions but are rarely placed at the centre of their design or monitoring.

Here, we argue that trees represent a major but underused opportunity for moth conservation. Although there is evidence that moths benefit from trees, it is currently scattered across separate literatures on urban ecology, agricultural landscapes, and forest management. As a result, the wider conservation message has been overlooked. Synthesising this evidence, we come to a simple conclusion: when tree identity, structure, connectivity and management are considered, trees have the potential to bend the curve of moth declines.

Tree retention and planting initiatives have expanded rapidly over recent decades under multiple policy goals[22], making this a critical moment to integrate moth conservation. In many countries, trees and forests are being retained, planted or restored across human-dominated landscapes. In cities, for example, trees are being promoted to make urban areas more habitable for humans, through cooling, air quality enhancement and mental wellbeing benefits[23–25]. Meanwhile, in farmlands, hedgerows and agroforestry are encouraged through agri-environment schemes for flood mitigation, crop protection and to boost biodiversity[26]. In remaining forests, management focus is moving beyond timber production by clear cutting to carbon offsetting, climate change resilience and biodiversity commitments[18,22,27,28]. Bringing together the evidence on how moths respond to these policy shifts in different treescape contexts provides essential information to ensure that urban tree planting and management creates practical and timely routes to conserve and restore moth biodiversity.

Why do trees matter for moths?

There are several ecological reasons why moths respond positivity to trees. First, trees provide resources across the moth life cycle (Fig. 1). Many moth species use trees as larval hostplants[29,30]. For example, a study of larval hostplants of over 12,000 Lepidoptera species in the United States found that five plant genera, all of which were trees (*Quercus*, *Salix*, *Prunus*, *Betula* and *Populus*), supported a disproportionately high number of species[31]. Trees also create detritus and support fungi, lichens, algae and animal nests, which all provide larval food resources for additional moth species[32]. Furthermore, trees provide sites for pupation, overwintering, and refuge from predators. For adult moths, trees offer shelter[17] and food resources such as nectar, sap and fruit[3].

Second, trees can buffer moth communities from intensifying environmental pressures in human-dominated landscapes. Trees create distinct microclimates; woodlands stay cooler during the day than do open or built environments, but at night they remain warmer, more humid and more thermally stable[33]. The more moderate and stable climatic conditions created by trees buffer insects against extreme weather (e.g. heatwaves and droughts) and urban heat island effects and thereby increase climate change resilience[34–36]. Urban treescapes may also help mitigate negative impacts of artificial light at night on nocturnal moths[37].

Third, trees contribute to habitat and landscape structure. By adding vertical structure, plant diversity and habitat complexity, trees can counteract the simplification of landscapes[38–40]. At larger spatial scales, forest patches, hedgerows, treelines and solitary trees can increase habitat connectivity and help moths move between otherwise isolated resources[40–42]. Trees therefore support moths not only as hostplants, but as three-dimensional habitat structures benefiting development, survival, reproduction and movement[38] .

However, moth assemblages are not shaped solely by tree cover. Tree species composition and demographics, vegetation structure, canopy conditions, patch geometry and landscape context all influence moth communities[43–45] and forest management can drive community-level reorganisation[40,44–47]. Therefore, to integrate moth conservation effectively into tree policies, we must move beyond coarse metrics (e.g. hectares planted, amount of carbon stored) which do not necessarily predict biodiversity outcomes. Instead, we should be concerned with questions such as: are the tree species larval hostplants? Do they provide resources for adult moths? Are they embedded in connected networks of hedgerows, parks, gardens and forest fragments? Do management practices retain structure and complexity, darkness and climatic stability, understorey vegetation, leaf litter, deadwood, lichens and fungi?

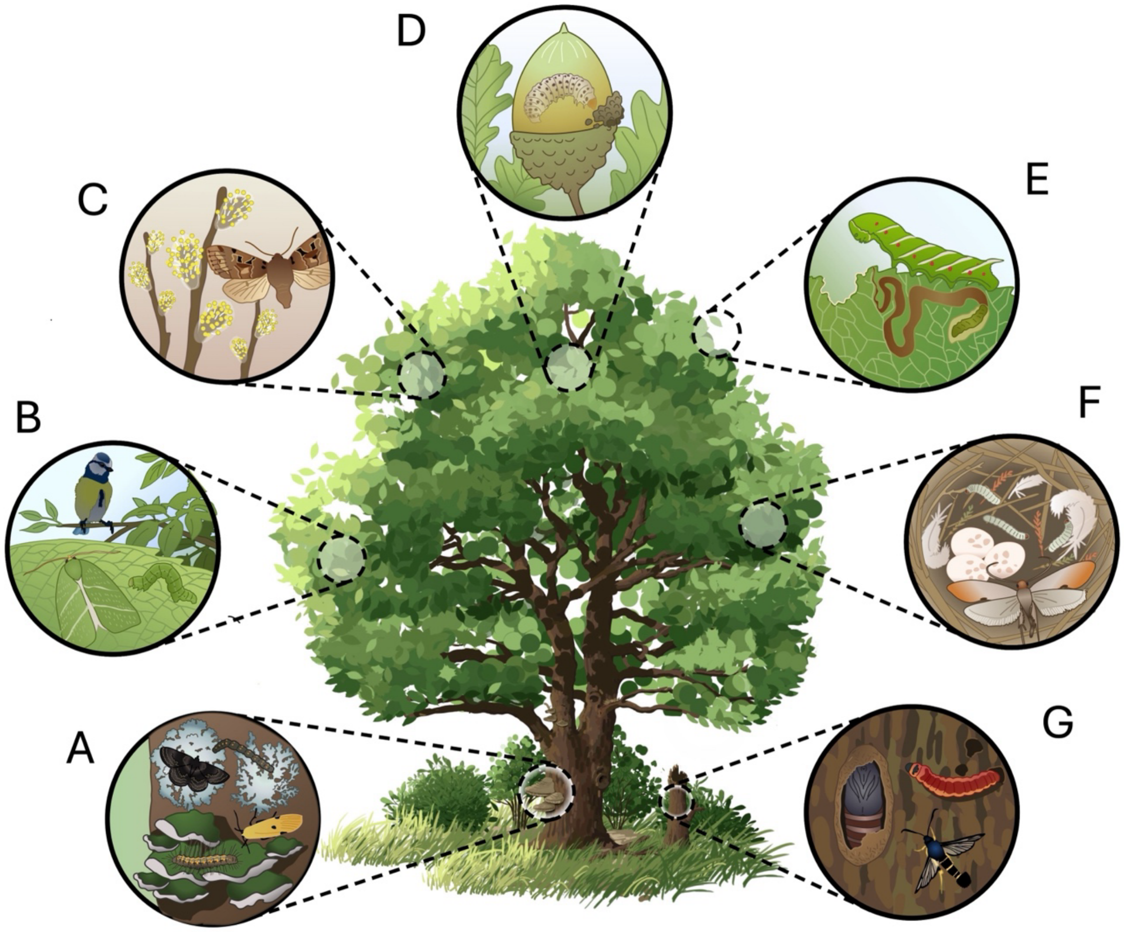

Figure 1: Trees provide resources and habitat for moths throughout their life cycle. Different parts of a tree support moths as feeding resources, shelter, breeding habitat and protection from predators. **(A)** Fungi, lichens and algae growing on trees provide larval food for species such as Waved Black (*Parascotia fuliginaria*) and Four-spotted Footman (*Lithosia quadra*). **(B)** Leaves and bark provide camouflage from predators; examples include Scarce Silver-lines (*Bena bicolorana*) and larvae of Winter Moth (*Operophtera brumata*), shown alongside a Blue Tit (*Cyanistes caeruleus*) predator. **(C)** Flowers provide nectar for adult moths, including spring-flying species such as Hebrew Character (*Orthosia gothica*) Blossom Underwing (*O. miniosa*), and Common Quaker (*O. cerasi*), which frequently visit willow (*Salix*) catkins. **(D)** Buds, flowers, fruits and seeds are exploited by many moth larvae, including *Pammene fasciana*, which develops within oak (*Quercus* spp.) acorns. **(E)** Foliage supports both external-feeding caterpillars, such as Eyed Hawk-moth (*Smerinthus ocellata*), and leaf-mining species such as *Stigmella oxyacanthella*. **(F)** Bird nests provide feathers and other organic detritus consumed by larvae of species including *Tinea semifulvella* and *T. trinotella*. **(G)** Wood and bark provide habitat for

internally feeding larvae, pupae and overwintering stages, including Goat Moth (*Cossus cossus*), Puss Moth (*Cerura vinula*) and Yellow-legged Clearwing (*Synanthedon vespiformis*). Examples are illustrative rather than exhaustive and drawn by Dr. Pinja Kettunen.

Trees to enhance urban moth populations

Urban environments offer particularly important opportunities for moth conservation, because they are where human pressure on biodiversity and human demand for nature converge. They are also where human–biodiversity encounters are most frequent, and where conservation outcomes can be showcased to the most people[48]. Globally, people are becoming more urban, driving habitat loss and fragmentation as towns and cities expand[49]. Increasing urbanisation is associated with lower moth abundance and diversity [50–55], contrasting with more mixed responses in some diurnal pollinators such as bees and hoverflies [56,57]. Urban moths face a combination of habitat fragmentation[54], vegetation simplification[5], artificial light at night[37] and urban heat island effects[58,59]. These pressures act through physiological, behavioural and community-level pathways: for example, urban warming alters development and activity periods [58], artificial light disrupts nocturnal moths across their life cycle[60], and changes in plant composition along increasing urban gradients can remove the larval hostplants and adult nectar resources needed to sustain populations[3,61].

At the same time, urban areas offer possibilities for moth conservation, both through the growing interest in urban biodiversity[62] and environmental improvements to enhance the quality of life for humans. Interventions to boost urban insect biodiversity have tended to focus on diurnal pollinators and the provision of floral resources, and their impact on moths has been rarely assessed. A recent synthesis of 28 European datasets found generally positive effects of urban pollinator interventions, but did not assess moths separately, highlighting the scarcity of evidence for nocturnal Lepidoptera[63]. The few studies that have experimentally tested how urban moths respond to such interventions suggest that reduced mowing may benefit moths[55], but flower-based interventions alone may be insufficient to enhance moth communities[19]. As a general rule, Lepidoptera shift resource use between the larval and adult stage, and thus a myopic focus on one or the other is unlikely to produce the desired outcome. Rather, maintaining access to both larval and adult resources is critical[64]. Here, promoting trees and shrubs can strike an ideal compromise, since trees may offer both nectar and foliage resources. Indeed, a comparison of plant visitation networks shows that moths make greater proportional use of tree and shrub flowers, whereas bees predominantly visit herbaceous flowers[3].

Evidence from the limited urban literature points consistently toward the importance of trees, shrubs and structurally complex vegetation for moth communities. In domestic gardens, moth abundance and diversity increase with local habitat complexity[5]. At broader urban scales, tree cover appears more important for moths than other pollinator groups. For example, Ellis et al.[56] found that moth species richness and abundance increased with tree cover in three English cities, but bees and hoverflies showed no correlation. Lintott et al.[54] found that mature, broadleaved, urban forest fragments supported the richest moth assemblages, while large, compact patches with less exposed edge supported higher moth abundance than smaller and more complex-shaped ones. Importantly, local woodland quality was more influential than the wider urban matrix. Narango et al.[30] showed that the tree composition of urban forest fragments can mitigate negative effects of urbanisation on moth communities, with the area of Lepidoptera host trees predicting moth abundance, diversity and biomass.

The evidence that urban biodiversity interventions for moths should focus on trees creates a strong conservation opportunity, because street/park trees and urban forests are increasingly promoted to make cities cooler, cleaner and more liveable for people[23,24,65]. The challenge is to ensure that urban trees are treated not only as climate, health or amenity infrastructure, but also as ecological structures beneficial to moths and other biodiversity. However, because the urban evidence base is still sparse, information from forest and agricultural systems can help to design urban treescapes that better support moths.

Lessons from agriculture and forestry: connectivity and management

Agricultural landscapes are useful analogues because, like urban areas, they comprise of patches of habitat set in hostile, simplified matrices. Here, too, trees emerge as key predictors of moth communities. Merckx et al.[17] found positive effects of field margin trees on macro-moth abundance, species richness and diversity. These effects appeared driven both by access to larval hostplants and by access to shelter and suitable microclimate. Adjusting the timing and reducing the frequency of hedgerow trimming also benefits moth abundance[41]. At the landscape scale, forest area, connectivity, and amount of forest edge further enhance moth communities[41,66]. Solitary trees and small fragments can function as stepping stones for moth movement across farmland[40], while greater tree cover can reduce the negative impacts of land use intensity on moth biodiversity[67]. These findings can be transferred directly to urban treescapes, as well as providing recommendations to improve agri-environment schemes for moths by incentivising the retention and restoration of mature trees and hedgerows.

Research on forest moth communities also provides important lessons for urban settings. Several studies have stressed the importance of maintaining core areas of closed-canopy forest less affected by edge effects[54]. In Belgium and France, forest edges supported 46% less macro-moth abundance and 29% less species richness than forest interiors, and management that opened up the forest canopy amplified reductions in moth abundance at edges[36]. Studies in British forests found that the sheltered, unfragmented interiors of mature deciduous woodlands were characterised by high moth abundance and species richness, while also providing essential habitat for many specialist and scarce species[40,44]. Where new forest patches are created, the tree species composition, structure and landscape context will affect the emerging moth communities[68,69]. In boreal Finland, Várkonyi et al.[70] found that both a habitat generalist and a forest specialist moth favoured old-growth spruce forest corridors during movement and tended to avoid the surrounding matrix. Combined with movement patterns of Lepidoptera in more open landscapes[40,42], these findings are particularly relevant for urban areas, where forest patches tend to be small and fragmented. Protecting the closed-canopy forest core and, wherever possible, increasing the size and connectivity of remnant patches through natural regeneration or tree planting will maximise benefits for urban moths.

Future directions:

Urban tree planting is accelerating in many countries, along with the retention of extant trees. For example, the EU Biodiversity Strategy for 2030 calls on towns and cities to develop ambitious urban greening strategies and highlights the key role of urban trees[71]. The EU Nature Restoration Regulation requires no net loss of urban tree cover by 2030, and a steady increase thereafter[22,28]. These policies are not designed for moths, but they will shape the habitats available to moths for decades.

Currently, the measures of tree policy implementation remain too coarse. Hectares planted, canopy cover gained or carbon stored do not predict biodiversity outcomes. A co-beneficial tree policy for moths and humans in urban environments would therefore follow four principles: 1) Protect features which cannot be recreated quickly: veteran trees, fragments of ancient forest and mature forest interiors. 2) Improve quality by planting trees that host many moth species and increasing vertical structure and habitat complexity. 3) Plan across urban landscapes, using hedgerows, treelines, solitary trees and small patches to connect larger woodland cores. 4) Monitor moth communities so that policy outcomes distinguish genuine recovery from community turnover or the loss of specialists. These approaches should complement, not replace, flower-rich urban interventions for diurnal pollinators. By combining urban greening with lessons from agriculture and forestry, urban areas could become a test case for moth-friendly tree policy across human-dominated landscapes.

More trees alone will not solve moth declines. Some moths require grasslands, wetlands, heathlands or early successional habitats, and natural regeneration or poorly targeted tree planting can harm these communities[21]. But we argue that trees represent disproportionately important habitats for moths in urban areas, as well as in the countryside, providing larval hostplants, shelter, microclimatic buffering and connectivity. Most importantly, this presents an alignment with current policies driven by wider environmental factors, providing opportunities to ensure that expanding treescapes also bend the curve of moth declines.

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