Received: 20 September 2025 | Accepted: 13 October 2025

DOI: 10.1111/1365-2656.70165

RESEARCH HIGHLIGHTS

BRITISH ECOLOGICAL SOCIETY Journal of Animal Ecology

Computer vision uncovers trait-based insect responses to habitat loss

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Handling Editor: Mariano Rodriguez-Cabal

Abstract

Research Highlight: Colares, L. F., Peres, C. A., Dambros, C. S. (2025). Life history induces markedly divergent insect responses to habitat loss. *Journal of Animal Ecology*. https://doi.org/10.1111/1365-2656.70117. Habitat loss is driving biodiversity collapse worldwide. Although this phenomenon has been extensively studied across many taxa and regions, we still lack information about whether species with distinct life histories respond differently to habitat loss. This challenge is particularly critical for tropical insects, where knowledge gaps remain large due to the Linnean (taxonomy) and Raunkiæran (traits) shortfalls. In this issue, Colares et al. (2025) address these gaps by using 236 sticky traps across the world's largest man-made tropical forest archipelago in the Central Amazon (~360,000 ha), generating a dataset of ~23,000 individual insects. They combined these surveys of insect fauna with computer vision models to assess how habitat loss affects both α- and β-diversity in insects with contrasting life histories (terrestrial vs. aquatic). The study reveals that responses diverge strongly depending on whether taxa rely on terrestrial or aquatic environments during their ontogeny. Whereas low forest amount reduced the number of terrestrial species, it increased species with aquatic life histories. Importantly, the authors also linked insect responses to body size (a proxy for dispersal ability), suggesting that larger insects, which disperse more successfully across the water matrix, may be favoured as 'winner' species in fragmented habitats. The findings of Colares et al. (2025) have broad implications for animal ecology and insect conservation. First, they highlight that insect declines in response to habitat loss are largely driven by traits that confer high or low resilience to reductions in forest cover. Second, they underscore the potential of computer vision as a powerful tool for uncovering key information about insect populations, thereby facilitating applied research such as rapid biodiversity surveys and long-term monitoring.

KEYWORDS
computer vision, deep learning, habitat loss, trait-based ecology, tropical insects

All authors contributed equally to this manuscript.

Habitat loss is one of the primary drivers of biodiversity decline across spatial scales (Betts et al., 2017; Chase et al., 2020; Fahrig, 2013; Gonçalves-Souza et al., 2025). Smaller habitats—whether oceanic or man-made islands, forest or moss fragments, ponds or microcosms—consistently harbour fewer species than larger habitats (Haddad et al., 2015 and references therein). This pattern is well captured by the theory of island biogeography, which posits a universal positive species–area relationship (Macarthur & Wilson, 1967). The simplest yet most powerful way to test this prediction is by counting the number of species in habitat patches of different sizes, an approach that has influenced numerous studies in ecology and conservation (Figure 1a). However, we still lack a clear understanding of how universal these patterns are beyond species richness at the patch scale (i.e. α-diversity) (Bender et al., 1998; Chase et al., 2020; Fahrig, 2013). For instance, it remains debated whether landscapes composed of multiple habitats accumulate more species overall, that is, γ-diversity (Fletcher Jr. et al., 2023; Horváth et al., 2019; Riva & Fahrig, 2023), and which traits make organisms more or less prone to extinction. More generally, some studies suggest that habitat loss favours certain 'winners', such as generalist or fast-growing species, whereas 'losers', including top-predators, specialists or large-bodied species, may

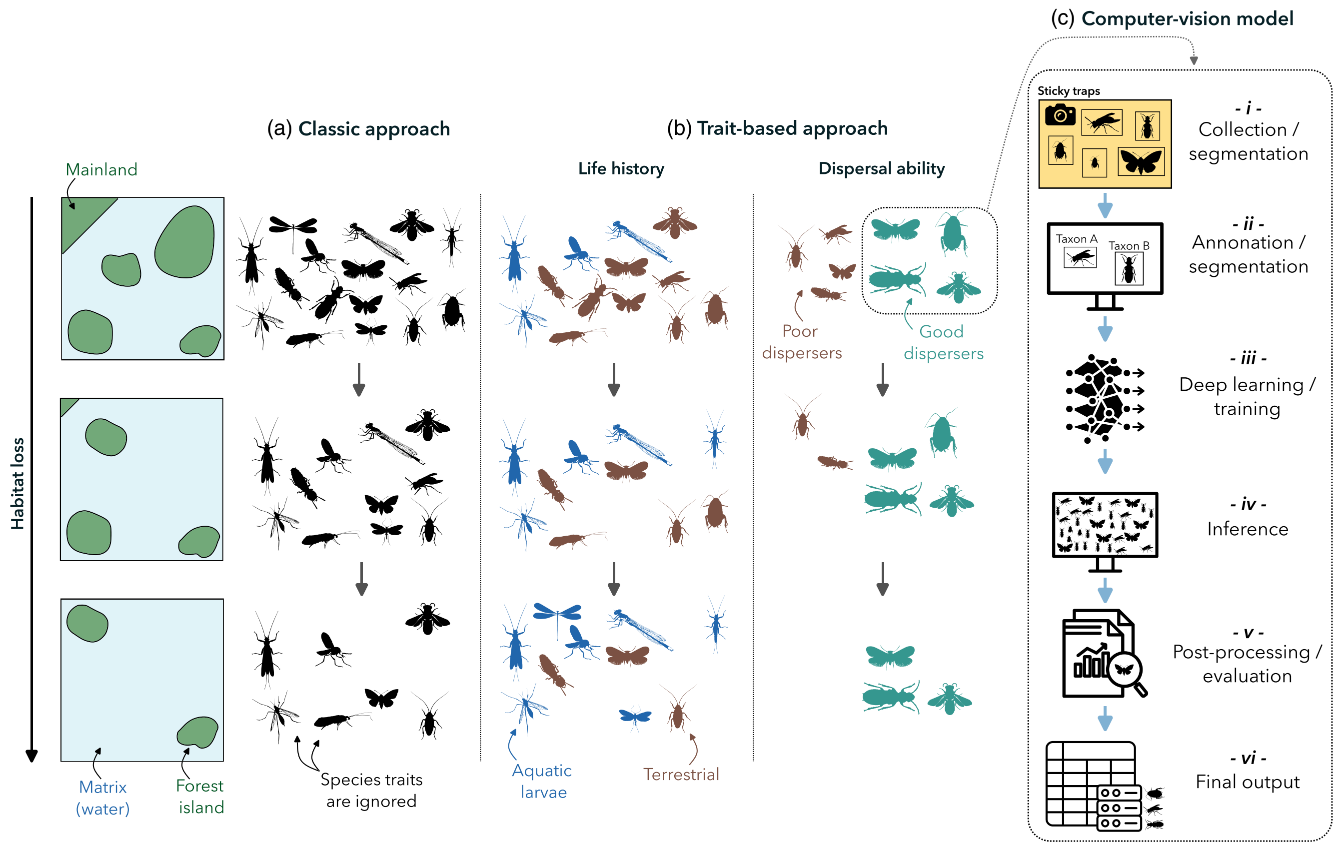

FIGURE 1 Conceptual diagram synthesizing two approaches to assess the effects of habitat loss on biodiversity. The left panels represent three landscapes with contrasting proportions of forest and water (matrix), illustrating a gradient of habitat loss from top to bottom. (a) In the classic approach, studies compare one or multiple taxonomic groups across landscapes to test whether the amount of habitat influences species richness. (b) In the trait-based approach, specific traits are predicted to mediate species' responses to habitat loss. For instance, terrestrial organisms (brown silhouettes, middle panel) are less able to move between forest islands and are therefore more negatively affected than aquatic insects (blue silhouettes, middle panel). Similarly, among terrestrial organisms, good dispersers (green silhouettes, right panel) can better colonize distant islands than poor dispersers (brown silhouettes, right panel), highlighting conditional responses to habitat loss driven by trait differences. (c) To identify species and measure insect traits, the authors implemented a computer vision pipeline consisting of the following steps: (i) *Image collection and segmentation*: Standardized 472 photographs of sticky traps containing insects were taken and further split into sub-images to isolate individual specimens; (ii) *annotation, segmentation and training data*: Insects were isolated in 14,090 image segments, of which 999 were annotated with bounding boxes, labelled by taxonomic group and partitioned into training and test datasets; (iii) *deep learning model training*: A YOLOv8 object detection model was trained with cross-validation on the annotated dataset; (iv) *inference on the full dataset*: The trained model was applied to all trap images using SAHI tiling to detect, identify and measure insect traits; (v) *post-processing and evaluation*: Detections were refined through IoU filtering, calculation of precision/recall/F1 metrics and removal of non-insect objects; and (vi) *final output*: Yielding approximately 23,000 insect detections with corresponding trait measurements and taxonomic identifications. Silhouettes from Phylopic (http://phylopic.org/), as a courtesy of Guillaume Dera, T. Michael Keesey, Margot Michaud, Melissa Broussard, Kamil S. Jaron, Nathan Jay Baker, Caleb M. Gordon, Mathieu Pélissié and Felix Vaux. Icons from Noun Project (https://thenounproject.com/).

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become locally extinct (Bender et al., 1998; Davies et al., 2004). This trait-mediated replacement of species under habitat loss has gained increasing attention (Filgueiras et al., 2021; Newbold et al., 2013; Pinho et al., 2024; Slade et al., 2013), yet it is striking that these questions remain unresolved across many systems and taxa, particularly tropical insects (e.g. Leal et al., 2012).

Most studies, though not all (see, e.g. Filgueiras et al., 2021; Henle et al., 2004; Leal et al., 2012), have not accounted for species trait differences in responses to habitat loss and have focused predominantly on plants, birds and mammals. Consequently, it remains unclear whether trait-mediated species replacement generalizes to other taxonomic groups such as insects. For tropical insects in particular, major knowledge gaps, including taxonomic uncertainty (the Linnean shortfall) and limited trait data (the Raunkiæran shortfall), have slowed progress in understanding how these organisms respond to habitat loss (see, e.g. Didham et al., 1998; Leal et al., 2012; Ribas et al., 2005). Previous studies have suggested that habitat loss decreases functional diversity by disproportionately removing specialist predators, climate specialists and poor dispersers (Leal et al., 2012; Tscharntke et al., 2002). However, because most of these studies focused on a single taxonomic group, our ability to generalize these responses across taxa remains limited. Furthermore, given the global evidence of insect declines in response to land-use change and climate change (Raven & Wagner, 2021; Wagner et al., 2021), it is imperative to improve our ability to predict which species (and which traits) are most sensitive to habitat loss, thereby enhancing efforts to protect and manage insect biodiversity.

Colares et al. (2025) addressed these gaps using a trait-based approach that combined field sampling with computer vision to assess how habitat loss affects α- and β-diversity of insects differing in life history (terrestrial vs. aquatic) and body size. They also tested whether insects in isolated forests surrounded by a higher proportion of water matrix exhibit larger body sizes (a proxy for dispersal ability in flying insects) than those in sites densely covered with forest islands (Figure 1b). Their study focused on the world's largest man-made tropical forest archipelago in the Central Amazon, where insects were collected across 17 forest islands and three continuous forest sites, using 236 sticky traps. Forest cover was quantified using concentric buffers to capture variation in habitat amount around each site.

The study by Colares et al. (2025) makes three key advances over the predominant literature on habitat loss. First, it integrates computer vision models (YOLOv8) to automatically identify insects and estimate body sizes, enabling the processing of ~23,000 specimens in less than 6 months and overcoming the traditional bottleneck of insect identification and trait measurement (Figure 1c). Second, it contrasts species with distinct abilities to move through the landscape matrix (in this case, water), providing insights into how dispersal mediates responses to habitat loss. Third, it accounts for differences in community evenness and species pools when calculating α- and β-diversity through coverage-based rarefaction, thereby reducing sampling bias (see, e.g. Chase et al., 2020; Gonçalves-Souza et al., 2025).

Colares et al. (2025) found that insect responses to habitat loss were strongly dependent on both taxon and trait. First, the abundance of terrestrial taxa (e.g. bees, wasps, cicadas and flies) increased with forest amount, whereas the abundance of aquatic groups declined. Second, forest amount positively affected the α-diversity of terrestrial insects but reduced the α-diversity of aquatic insects. Third, forest amount shaped community composition (β-diversity), with terrestrial 'loser' species being replaced by aquatic 'winner' species in landscapes with less forest. Interestingly, shifts in both α- and β-diversity persisted even after controlling for sampling effort (i.e. accounting for differences in abundance and regional species pool size).

There are several important implications of this study: (1) By comparing insects from distinct taxonomic groups with contrasting life histories, it shows that responses to habitat loss diverge strongly depending on whether taxa rely on terrestrial or aquatic environments during ontogeny. More broadly, if these results are generalized to terrestrial fragments embedded in different types of matrices (e.g. agroforests, croplands or urban areas), they may help identify mechanisms underlying biodiversity impoverishment—where only a few species persist in fragmented landscapes—and the replacement of 'loser' species (often specialists and top predators) by 'winner' species (typically generalists and fast-growing taxa). (2) It explicitly links a pivotal trait in animal ecology, body size, to species' ability to thrive or decline in response to habitat loss. (3) It highlights deep learning and computer vision as powerful tools for estimating diversity patterns in hyperdiverse regions such as the tropics. (4) It reinforces the importance of large, continuous forests for sustaining diverse insect communities and provides actionable insights for conservation policy in tropical landscapes. In summary, this study advances understanding by integrating deep learning, large-scale field sampling and life-history and morphological traits to reveal how habitat loss differentially affects insect groups, thereby addressing gaps in trait-based insect ecology, conservation planning and methodological approaches.

Beyond theory, Colares et al. (2025) highlight how simple sticky traps combined with deep learning can deliver rapid, scalable estimates of insect abundance, diversity and body size across vast tropical landscapes. This potential is illustrated by the Project Artificial Intelligence for Recognizing the Amazonian Environment (IARAA; led by the first author from Colares et al., 2025), which aims to use artificial intelligence and build low-cost open-source equipment to detect and monitor multiple taxa in the Amazon. Their approach contributes to the growing wave of automated biodiversity monitoring frameworks (for recent reviews, see Besson et al., 2022; van Klink et al., 2024) and could be extended to restoration monitoring, as well as deployed across gradients and seasons to capture large-scale biodiversity dynamics in tropical systems. Looking forward, integrating rapid biodiversity surveys with rapid ecosystem function assessments (REFA; Meyer et al., 2015) could enable whole-ecosystem assessments that directly link biodiversity change to ecosystem multifunctionality. By scaling up biodiversity ecosystem-functioning monitoring, researchers and practitioners gain a powerful tool to anticipate 'winner–loser' dynamics (Filgueiras et al., 2021; Newbold et al., 2013; Öckinger et al., 2010; Pinho et al., 2024) and to identify leverage points for sustaining biodiversity in a rapidly changing world (Abson et al., 2017; Martin et al., 2022). It is important to acknowledge the limitations of deep learning approaches, particularly in regions harbouring rare or cryptic species. Nevertheless, these methods are advancing rapidly (Borowiec et al., 2022; Karbstein et al., 2024). Moreover, computer vision-based identification and measurement rely on labelled datasets, making it essential to continue supporting taxonomic expertise, especially for hyperdiverse groups such as insects.

Colares et al. (2025) show that habitat loss reshapes insect communities not only by reducing richness but also by shifting trait distributions, producing a consistent 'upsizing' effect linked to life history and dispersal ability. This finding aligns with recent trait-based extensions of island biogeography, which emphasize the role of functional traits in shaping dispersal, colonization and persistence (Ottaviani et al., 2025; Schrader, 2025; Schrader et al., 2020). A key next step is to test whether habitat loss generates functionally disharmonic communities (König et al., 2021; Taylor et al., 2019), where insect trait composition on forest islands systematically diverges from that of continuous forests. Colares et al.'s system, spanning a gradient from intact mainland forest to islands with varying forest cover, offers a unique opportunity to test if over- or under-representation of certain taxa linked to dispersal differences intensifies with habitat loss and whether such filtering leaves a detectable functional signature. Ultimately, linking these trait shifts to ecosystem functions such as pollination, seed dispersal, pest control and decomposition will be crucial for understanding how the exclusion of certain traits due to habitat loss cascades into broader ecosystem functioning. In practical terms, Colares et al. (2025) show that combining sticky traps with computer vision enables rapid biodiversity surveys and could transform how we manage and protect insect biodiversity, particularly in hyperdiverse ecosystems such as the Amazon (e.g. Albert et al., 2023; Lapola et al., 2023).

AUTHOR CONTRIBUTIONS

All authors wrote the manuscript. TG-S prepared the figure with inputs from all authors.

ACKNOWLEDGEMENTS

We thank Lucas F. Colares and Carlos A. Peres for kindly revising the first draft of the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

The authors have no data to report.

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How to cite this article: Gonçalves-Souza, T., Vancine, M. H., & Paterno, G. B. (2025). Computer vision uncovers trait-based insect responses to habitat loss. *Journal of Animal Ecology*, *00*, 1–5. https://doi.org/10.1111/1365-2656.70165