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# Landscape composition drives taxonomic and functional diversity of bats and small rodents in human-modified tropical landscapes

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## HIGHLIGHTS

- Land-use changes are transforming tropical forests into heterogeneous landscape mosaics with various anthropogenic land covers.
- Urban cover is the main landscape factor negatively impacting bat and small rodent taxonomic and functional diversity.
- Functional diversity of both taxa decreases with increasing urban cover, filtering out more specialized species.
- Forest cover favored some unique functional attributes in bats, increasing their functional diversity.
- Preventing urban expansion and deforestation, while maintaining forest cover and forest remnants are urgent strategies.

## ARTICLE INFO

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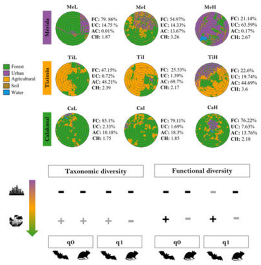
## GRAPHICAL ABSTRACT



## ABSTRACT

Land-use changes are rapidly transforming tropical forests into heterogeneous landscape mosaics with different anthropogenic land covers, leading to species loss and the disruption of their ecological functions. While the impact of landscape composition on taxonomic diversity is well documented, its influence on functional diversity remains poorly understood. This is particularly relevant for species like bats and rodents, which play essential ecological roles in both natural and human-modified ecosystems. To address this knowledge gap, we used a multi-model inference approach to assess the influence of landscape composition metrics measured across seven spatial scales on bat and small rodent diversity in the Yucatán peninsula, a highly deforested biodiversity hotspot. Our findings indicate that urban cover is the main factor negatively impacting the taxonomic and functional diversity of both taxa. Urban expansion impacts on small rodents were related to their limited dispersal capacity and small home ranges and the high dependence of arboreal rodents on forested habitats. Forest cover was

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mainly related to bat functional diversity, positively affecting forest-specialist species. Therefore, landscape modification, especially urbanization, threaten bat and rodent diversity even in landscapes with higher forest cover, highlighting the importance of assessing both taxonomic and functional diversity to develop effective conservation strategies in human-modified landscapes. Management strategies are needed to mitigate these negative impacts, including maintaining forest remnants and increasing overall forest cover. The persistence of bat and rodent assemblages are essential for the health and resilience of forest ecosystems, as they provide crucial functions such as herbivory, predation, seed dispersal and pollination.

## Introduction

Most tropical forests are experiencing high rates of deforestation, negatively affecting biodiversity and ecosystems processes (Theobald et al., 2020). As a result, an increasing proportion of tropical landscapes has been transformed into heterogeneous mosaics, where forest remnants are surrounded by anthropogenic land covers (e.g., agricultural and urban areas; Melo et al., 2013). Understanding how species respond to changes in landscape composition, namely the types and proportions of each land cover, is fundamental to inform public policies and guide biodiversity conservation in these human-modified landscapes (Arroyo-Rodriguez et al., 2020; McGarigal et al., 2023). Among these changes, forest loss is one of the most important means of landscape modification, as it reduces resource availability, disrupts ecological functions and drives substantial biodiversity loss. These effects, however, are partially mitigated when the surrounding anthropogenic matrix retains forest habitats, which are key to maintain forest-dwelling species (Arroyo-Rodriguez et al., 2020). For instance, both old-growth and secondary forests, as well as scattered trees, can provide a variety of resources that organisms may use throughout the landscape (Arce-Peña et al., 2022; Larson and Sander, 2024). Although old-growth and secondary forests differ in structure and composition, they can play complementary roles in providing shelter, food and connectivity for wildlife. In fact, as each land cover type may offer different complementary and/or supplementary roles in providing shelter, food and connectivity for wildlife resources (Dunning et al., 1992; Fahrig et al., 2011), it is reasonable to expect that landscapes with more heterogeneous matrices should support a higher number of species when compared to landscapes with more homogeneous matrices (Fahrig et al., 2011; Willig et al., 2019). Therefore, assessing the relative importance of landscape composition and heterogeneity is critical to better evaluate species responses of ecologically relevant taxa such as bats and rodents.

Bats and small rodents are known to respond in complex ways to landscape changes (Presley et al., 2019). For example, studies have shown that the taxonomic diversity and community composition of both groups can be shaped by landscape composition (Arroyo-Rodríguez et al., 2016; Arce-Peña et al., 2022; Morales-Díaz et al., 2019; Carvalho et al., 2020; Paniccia et al., 2022). However, to date the effects of landscape composition on the functional dimension of bat and small rodent diversity remain poorly understood (Farneda et al., 2024; Paniccia et al., 2022). Functional diversity measures the variation in ecological traits within assemblages, including traits that are critical to species' performance in specific habitats (Cadotte et al., 2011). In tropical environments, for instance, bats and small rodents exhibit a wide range of functional traits that underpin their essential ecological roles, such as herbivory, predation, soil aeration, pollination, and seed dispersal (Kunz et al., 2011; Lacher et al., 2019; Presley et al., 2019; Godó et al., 2022). Therefore, it is crucial to assess their functional response to landscape changes, which can provide valuable and complementary information for preserving these taxa and their ecological functions in human-modified landscapes (Magioli et al., 2016; Paniccia et al., 2022). However, it is important to note that, depending on the species' vagility, each taxon may be affected by landscape compositional variables measured at different spatial scales (Miguet et al., 2016). Hence, although bats and small rodents interact with compositional variables of the surrounding landscape, the scale at which such interaction is strongest (the scale of effect) will vary in association with different traits, among which vagility and specialization may play a significant role (see Miguet et al., 2016).

The Yucatán peninsula, Mexico, is a biodiversity hotspot with ≈60 bat species and 15 small rodent species (hereafter referred only as rodents; Sosa-Escalante et al., 2013; Zaragoza Quintana et al., 2016). However, this region currently presents one of the highest deforestation rates in Mexico, having lost nearly 286,000 ha of forest cover in the last four years (Ellis et al., 2023). In this study we assessed the influence of four landscape compositional variables (i.e., forest cover, urban cover, agricultural cover, and compositional heterogeneity) on the taxonomic and functional diversity of bats and rodents in three regions with different patterns of land-use change within the Yucatán peninsula.

Following the predictions postulated by the landscape complementation and supplementation hypotheses (Dunning et al., 1992; Fahrig et al., 2011), we expect that forest loss and increasing urban and agricultural cover will decrease the taxonomic and functional diversity of bats and rodents. Yet, as the provision of complementary and/or supplementary resources can be higher in more heterogeneous landscapes, the taxonomic and functional diversity of both taxa should be positively related to compositional heterogeneity (Tscharntke et al., 2012). Finally, we expect the effects of land-use change will positively affect rodent taxonomic diversity (Godó et al., 2022), while negatively affecting the functional diversity of forest-specialized bats (Jung and Threlfall, 2018).

## Materials and methods

### Study area

The Yucatán peninsula is located in southeastern Mexico, including the Campeche, Yucatán and Quintana Roo states, where we studied three regions (Mérida, Tizimín, Calakmul) with different land-use patterns (Fig. 1; see Appendix S1 in Supplementary Material for a detailed description of each region). Within each region, we selected three landscapes with different levels of human-modification from more forested to more urbanized (L: low, I: intermediate, and H: high modification; Fig. 2). In Mérida (Me) we sampled three landscapes: (i) the campus of the Universidad Nacional Autónoma de México (MeL), which is surrounded by forest remnants; (ii) Ucú, a suburban settlement with agricultural and cattle farming (MeI); and (iii) the urban Archaeobotanical Park Anikabil (MeH) embedded in the city. In Tizimín (Ti) we selected (i) an open cenote (TiL) surrounded by secondary forest; (ii) a cattle ranch surrounded by cultivated pastureland (TiI), and (iii) Santo Domingo, a suburban area (TiH). In Calakmul (Ca) we sampled (i) Ejido Nueva Vida (CaL), classified as an Area Voluntarily Designated for Conservation, (ii) a logged area abandoned since ca. 10 years (CaI), and (iii) Zoh Laguna (CaH), a settlement adjacent to the Calakmul Biosphere Reserve surrounded by agroecosystems interspersed with forest remnants.

### Bat and rodent sampling

We sampled bats (Phyllostomidae and Mormoopidae families) and rodents in the center of each landscape for two consecutive nights during the dry season from November 2021 to May 2022. We captured bats using six mist nets (6m × 2.5m) placed $>$20 m apart at ground level and set in potential flight paths. The nets were opened at sunset, checked every 30 min, and left open for six hours to cover the peak of bat activity (total sampling effort was 1,080 m$^2$-hour per site; Romero-Almaraz et al., 2007). At the same time, we captured rodents with 120 Sherman traps, placed along random transects, with traps set 10 m apart. The traps remained active from dusk to dawn, and checked in early morning, for a total sampling effort of 240 trap-nights per site (Romero-Almaraz et al., 2007). All individuals were identified to the species level, sexed, and their standard morphological measures taken, and temporarily marked with a non-toxic gentian violet to avoid recaptures. All animals were immediately released at the sampling site and individual well-being was assured (see details in Appendix S2).

### *Response diversity variables*

To avoid pseudoreplication, we combined the taxonomic and functional information from all nets/traps within each landscape. Functional diversity was estimated using five functional traits related to bat and rodent vagility, foraging ecology, and space use, to effectively assess the impacts of changing landscape composition (Table S1). We gathered the information of the continuous traits from each individual captured, while that of the categorical traits was obtained from published literature. For bats, we included foraging guild (frugivore, nectarivore, sanguinivore, gleaning insectivore or aerial insectivore) and vertical stratification (canopy, understory or no preference). For rodents we selected habitat use (terrestrial, semi-arboreal, arboreal or semi-aquatic).

To estimate the taxonomic and functional diversity of each taxon, we used a unified framework based on Hill numbers, which represent the effective number of species and functional groups within a community (Chao et al., 2014; Farneda et al., 2024). This approach allowed us to quantify both taxonomic and functional diversity within the same conceptual and mathematical structure, facilitating direct and consistent comparisons across biodiversity dimensions. We considered three orders of diversity ($qD$): $q = 0$ measures the effective number of species or functional groups and is insensitive to species abundance; $q = 1$ represents the effective number of common species or functional groups, weighting each species according to its abundance and reducing sensitivity to rare species; and $q = 2$ represents the effective number of dominant species or functional groups, giving greater weight to the most abundant species (Chao et al., 2014). As sample coverage varied between landscapes, we estimated diversity values for $q = 0$ using rarefied diversity estimates based on sample coverage provided by iNEXT, which has been shown to provide reliable estimates in R 4.2.2 (Chao and Jost, 2012; Hsieh et al., 2016; R Core Team, 2022). Functional diversity analyses were performed using the mFD package (Magneville et al., 2022).

### *Landscape metrics*

We used Sentinel-2A satellite images (10 m resolution) and a supervised classification of land cover types in QGIS v.3.28.9 (QGIS, 2024), using spectral indices related to vegetation, soil, and artificial surfaces (full description of images processing in Appendix S3). We

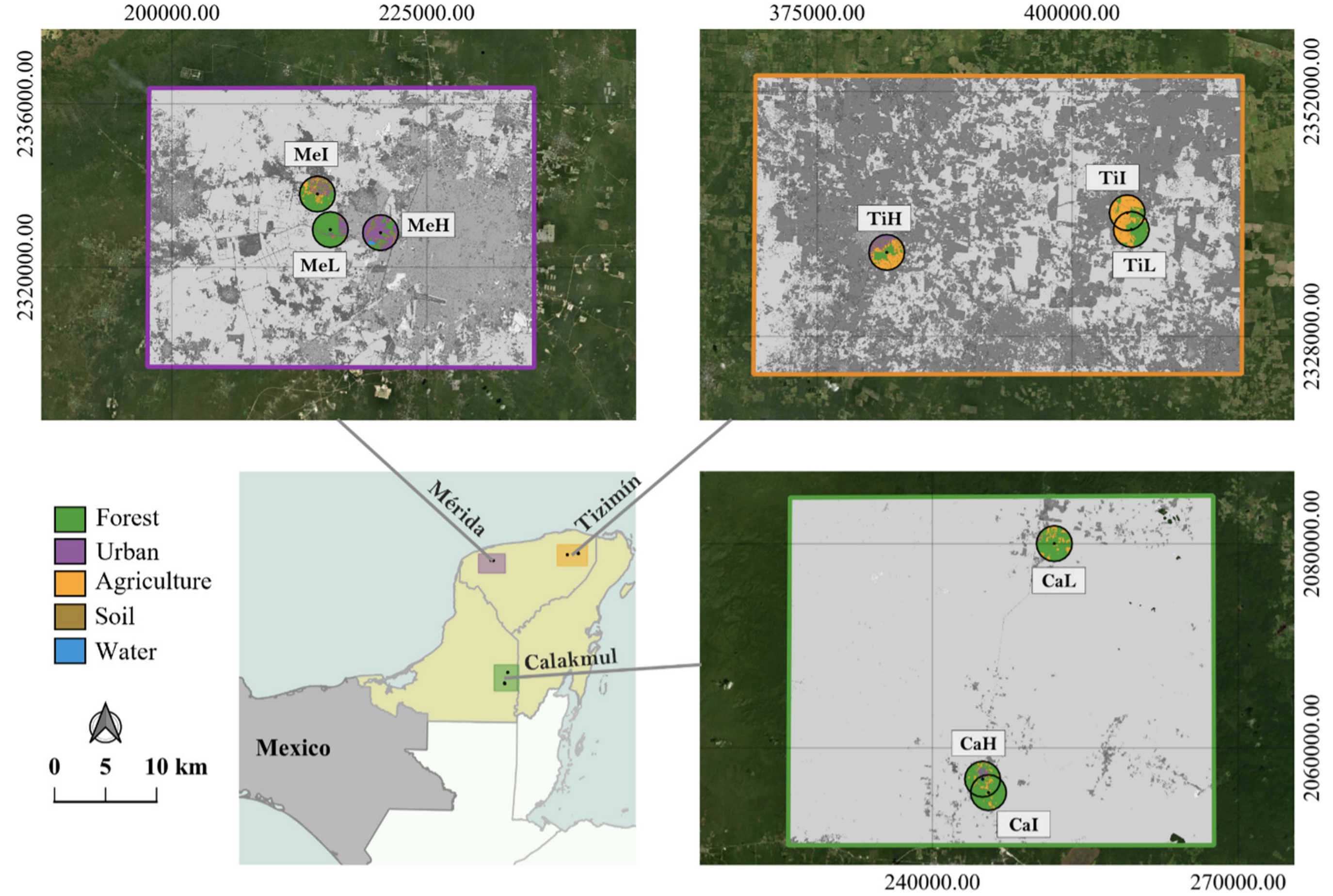

**Fig. 1.** Location of the study regions (Mérida, Tizimín, Calakmul) and sampling landscapes in the Yucatán peninsula, Mexico. We characterized the landscape at the center of each sampling site into the following land cover classes: forest (green), urban (purple), agriculture and cattle farming (orange), soil (brown), and water (blue). Landscape names include a regional code (Me, Ti, Ca) followed by a letter indicating low (L), intermediate (I), and high (H) landscape modification. See Fig. 2 for a full description of the composition of each landscape.

considered five dominant land cover types: water, forest, agriculture and cattle farming, urban, and soil. We combined old-growth and secondary forests into a single "forest" class because both forests are known to provide resources for bats and rodents (Farneda et al., 2024; Larson and Sander, 2024). We then quantified four landscape compositional variables: percentage of forest cover, percentage of urban cover, percentage of agriculture and cattle farming cover, and landscape composition heterogeneity, the latter measured as the Hill number of order 1, which is interpreted as the effective number of common land uses in the landscape (Carvalho et al., 2023). As we did not know the scale of effect of each of these landscape variables on each response variable a priori, we evaluated each landscape variable in seven concentric buffers per sampling site with Fragstats v.4.2 (McGarigal et al., 2023), ranging from 250 to 1750 m radius for bats, and from 200 to 1400 m radius for rodents based on their home ranges (Fig. 2; Avila-Cabadilla et al., 2012; Wilson et al., 2016, 2017). We did not explore larger scales as that would increase spatial overlap between sampling landscapes, thus reducing data independence (Zuckerberg et al., 2012).

### *Statistical analyses*

We first verified the spatial independence of sampling landscapes using Mantel tests and found no evidence of spatial structure in the data ($r < -0.24$, $p > 0.47$ in all cases; Table S2). We evaluated differences in species composition among landscapes and regions using Non-metric Multidimensional Scaling (NMDS), based on Bray-Curtis dissimilarities calculated from species identity and abundance data and a distance matrix between sampling landscapes. To assess whether forest cover was related to variation in community composition, we performed environmental fitting (envfit) using the vegan package in R (Avila-Cabadilla et al., 2012; Oksanen et al., 2024). Additionally, we applied Analysis of Similarities (ANOSIM) to statistically test for differences in community composition among regions, providing a complementary approach to evaluate whether community composition significantly differed (Alves et al., 2020).

To evaluate how landscape composition variables relate to species diversity, we first identified the scale of effect for each landscape predictor on each response variable, by performing univariate generalized linear models (GLMs) and selecting the model with the lowest AICc as the scale of effect for each predictor. To compare whether the scales of effect for taxonomic and functional diversity of bats and rodents differed, we estimated a Wilcox test (Cudney-Valenzuela et al., 2022). Next, we applied a multi-model inference approach using the glmulti package (Burnham and Anderson, 2002; Calcagno and Mazancourt, 2010) to assess the relative importance of each landscape predictor in explaining diversity metrics. The full model for each response variable included the four landscape variables measured at their respective scales of effect, after confirming their independence (variance inflation factor, VIF $< 2$ in all cases). To avoid overfitting, we considered all possible models with up to two predictors and compared using AICc. Models with a difference in AICc $<2$ were retained for model averaging. The null model was also included to assess whether predictor variables provided a better fit than no predictors. Finally, we calculated the relative importance of each predictor as the sum of Akaike weights across the best models. Predictors with a high summed Akaike weight and model-averaged parameter estimates with low unconditional variance were considered important. Model-goodness-of-fit was evaluated by the percentage of explained deviance relative to the null model (Burnham and Anderson, 2002; Crawley, 2013). All statistical analyses were performed separately for each mammal community using R.

## Results

A total 284 bats belonging to 13 native species were captured (Tables S3 and S4 provide a complete species list, their distribution and their traits). Species richness encompassed 41.9% (13/31 species) of the

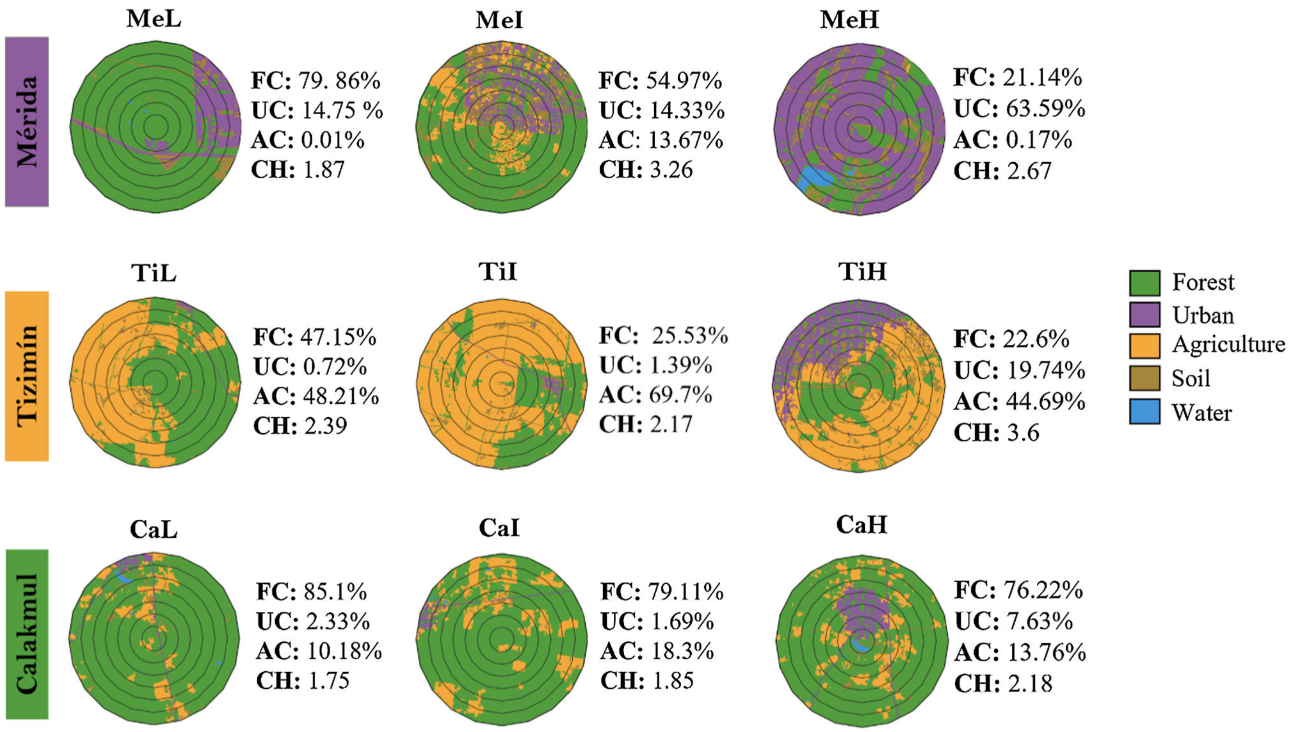

**Fig. 2.** Land cover types in each landscape and region (Mérida, Tizimín, Calakmul) studied in the Yucatán peninsula, Mexico. In each landscape, we quantified the percentage of the landscape area covered by different land covers (landscape composition), considering seven concentric spatial scales (radii ranging from 250 to 1750 m) from the centroid of all nets/traps within each sampling site. FC: forest cover (green), UC: urban cover (purple), AC: agriculture and cattle farming cover (orange), CH: compositional heterogeneity. The percentages provided correspond to the largest scale (1750 m radius). Landscape names include a regional code (Me, Ti, Ca) followed by a letter indicating low (L), intermediate (I), and high (H) landscape modification.

Phyllostomidae and Mormoopidae species reported for the Yucatán peninsula. *Artibeus jamaicensis* (94 individuals), *Artibeus lituratus* (56), and *Glossophaga mutica* (48) were the most abundant species. In contrast, three species (*Carollia perspicillata, Mimon cozumelae*, and *Micronycteris microtis*) were recorded only once in Tizimín, and one species (*Chiroderma villosum*) only once in Calakmul. NMDS ordinations showed that sampling landscapes from Tizimín and Mérida clustered together for bats, indicating higher similarity in community composition compared to Calakmul (Fig. 3a). Despite some compositional differences among regions and landscapes, the region only explained 36.2% of the variation in bat composition ($p > 0.05$). The forest cover gradient explained a larger portion (50%) of community dissimilarities, although this effect was not statistically significant ($p > 0.05$). Complementary ANOSIM analysis showed no significant differences in bat community composition among regions ($R = 0.13$; $p = 0.16$).

Regarding rodent assemblages, we captured 99 rodents from 10 native species and two exotics (*Mus musculus* captured in MeI landscape, *Rattus rattus* in TiH). The most abundant species varied by region: *Peromyscus yucatanicus* in Mérida (27 individuals), *Sigmodon toltecus* in Tizimín (22), and *Heteromys gaumeri* in Calakmul (9). Five species were recorded only in Calakmul (Tables S3, S4). The NMDS indicated significant differences in rodent composition among regions ($p = 0.003$; Fig. 3b). Forest cover accounted for 50% of the variation in rodent composition, but its effect was not statistically significant ($p = 0.13$). ANOSIM results indicated significant differences among regions for rodent community composition ($R = 0.58$, $p = 0.01$).

### Landscape predictors of taxonomic and functional diversity

The taxonomic and functional diversity of both taxa varied among landscapes. Bat species diversity varied from 1 to 11 species, being highest in TiL, the landscape with the lowest modification in Tizimín, and lowest in MeH, the most modified landscape from Mérida (Fig. 4, Tables S3, S5). Rodent species diversity ranged from 1 to 6 species, being highest in CaI (intermediate modification from Calakmul) and lowest also in MeH (Fig. 4). Most bat species were frugivorous (7 species, 78.9% of all individuals recorded); also, in terms of habitat use, 50% of bat individuals used both the understory and canopy strata (Table S4). Although other habitat use (semiaquatic, semiarboreal and arboreal) was also present, rodents were primarily terrestrial, representing 79.8% of individuals (7 species). Our data confirmed the landscape composition at the regional scale, showing a gradient of landscape modification from Calakmul with the highest forest cover to Mérida with the highest urban cover (Appendix S4; Fig. S1).

The scale of effect varied among landscape and response variables (Table S6) but was similar in bats (mean ± 95%CI = 1135 ± 253 m) and rodents (1167 ± 155 m) ($W = 342.5$, $p = 0.250$; Fig. S2). However, bats showed a broader range and confidence interval, likely reflecting interspecific differences in vagility, which is expected in community-level analyses. The multi-model averaging approach showed that

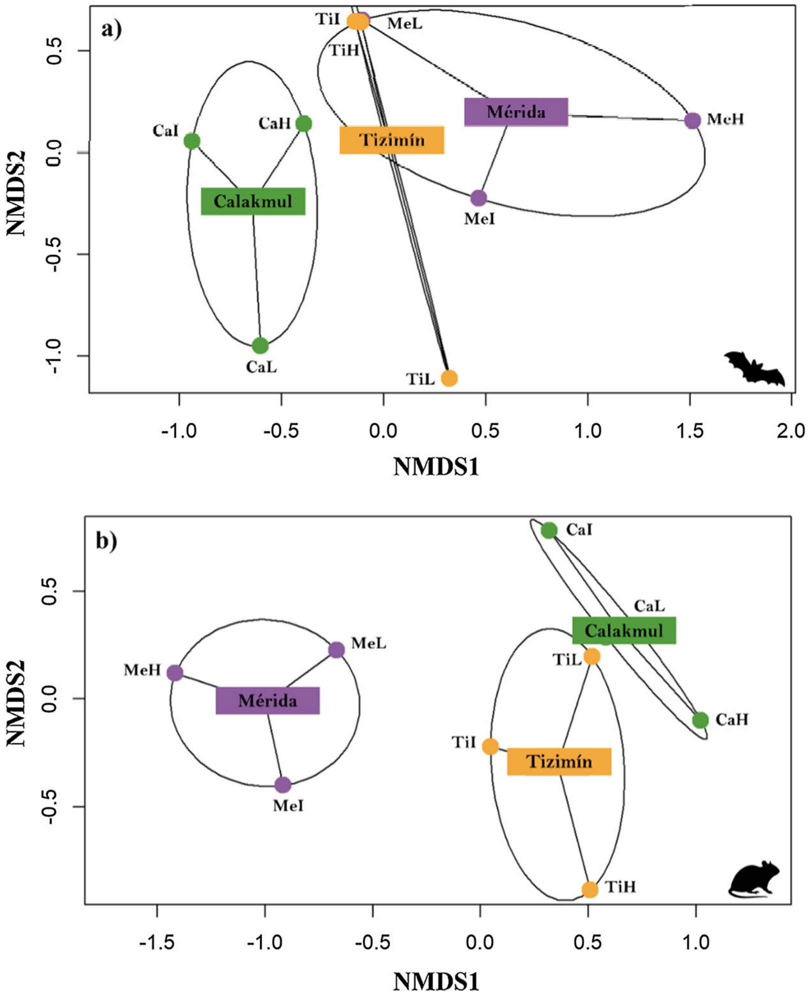

**Fig. 3.** Non-metric Multidimensional Scaling (NMDS) ordination based on species composition for (**a**) bats (stress value = 0.05) and (**b**) rodents (stress value = 0.06) at the nine sampling landscapes located in three regions (Mérida, Tizimín, and Calakmul) from the Yucatán peninsula, Mexico. Landscape names include a regional code (Me, Ti, Ca) followed by a letter indicating low (L), intermediate (I), and high (H) landscape modification.

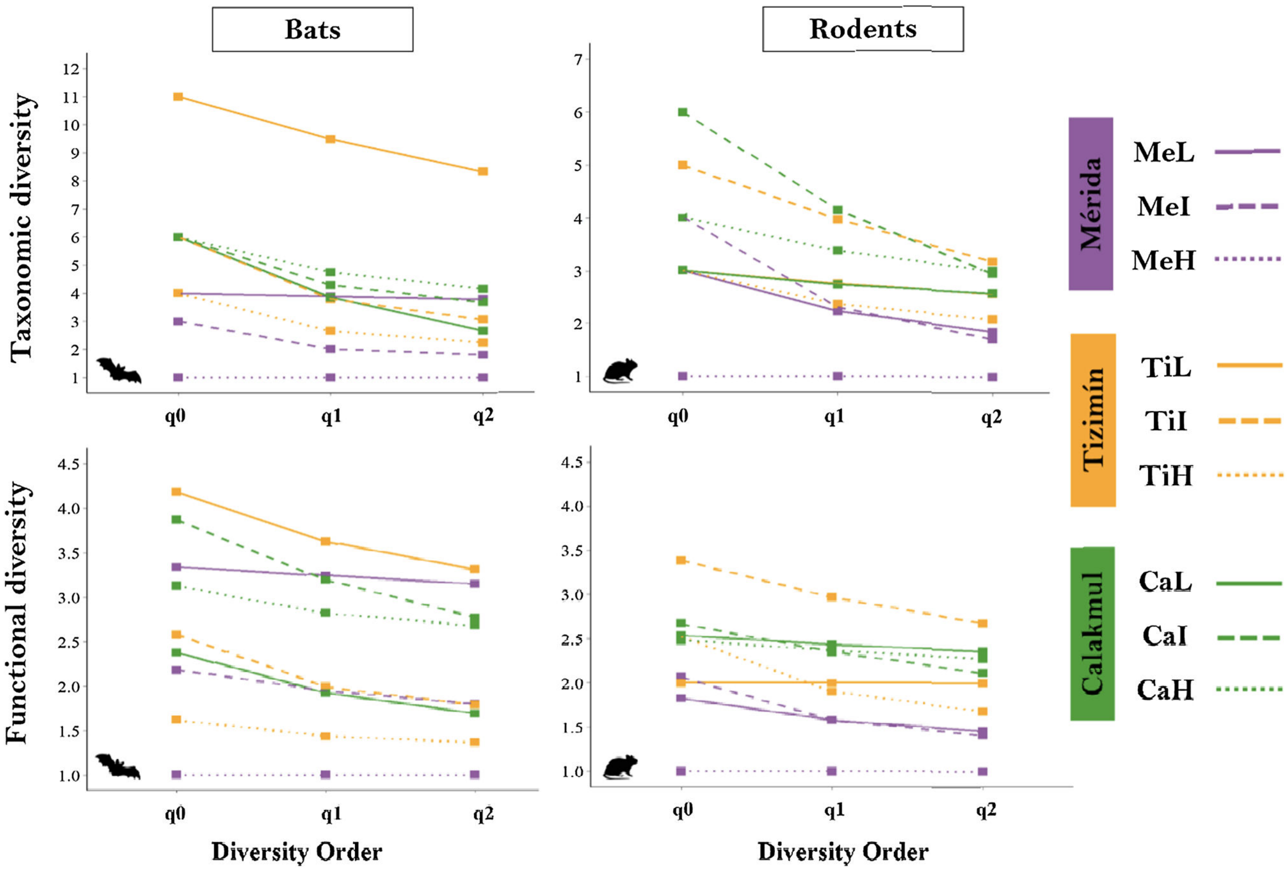

**Fig. 4.** Diversity profiles based on Hill numbers of order q0, q1 and q2 for taxonomic and functional diversity for bats and rodents from three regions on the Yucatán peninsula, Mexico. Colors depict each region and the sampling landscapes within (Mérida in purple, Tizimín in orange, Calakmul in green). Landscape names include a regional code (Me, Ti, Ca) followed by a letter indicating low (L), intermediate (I), and high (H) landscape modification.

urban cover was the most important landscape predictor, as it was included in the best models for most response variables, being negatively associated with taxonomic and functional diversity metrics (q0 and q1) for bats and rodents (Fig. 5, Tables S7, S8, Fig. S3). Urban cover was the only variable influencing diversity in rodents, while forest cover was positively associated with bat functional diversity (q0 and q1; Fig. 5). Taxonomic diversity of order 2 (q2) followed similar patterns for both taxa. The rest of landscape variables were much less important (Fig. S3, Tables S7, S8).

## Discussion

To our knowledge, this is the first study to assess small mammals' taxonomic and functional responses to landscape composition, using variables measured across different scales. Despite our relatively small sample size (n = 9 landscapes), we analyzed three regions with contrasting gradients of landscape modification and found strong evidence that urban cover is the main compositional variable negatively impacting the diversity of bats and rodents. As discussed below, this finding has critical ecological and applied implications.

The importance of urban cover for bats and rodents is not surprising. Both taxonomic and functional diversity decreased with increasing urban cover in the landscape. This can be explained by the fact that urban expansion occurs at the expense of the original forest cover, reducing availability of resources such as food and shelters, essential to maintaining species and their functional traits (Tscharntke et al., 2012; Meyer et al., 2015). Urban expansion also contributes to landscape fragmentation, intensifying edge effects and reducing connectivity between forest remnants and scattered trees. This further limits the movement of individuals and constrains landscape supplementation dynamics in human-modified landscapes (Dunning et al., 1992; Fahrig et al., 2011; Willig et al., 2019). Among the landscape variables evaluated, urban cover was the only factor influencing rodent diversity patterns, not only as a consequence of their low dispersal capacity and small home ranges (Godó et al., 2022), but also because arboreal rodents are highly dependent of forested habitats. The influence of urban cover on bat functional diversity affected the more specialized species, such as insectivores that are restricted to forested habitats, more than the highly mobile frugivores bats (Avila-Cabadilla et al., 2012; Ramírez-Mejía et al., 2020). Urban cover also impacted bat community composition, with landscapes MeL, TiI, and TiH showing high community similarity despite their different forest cover percentages. For example, MeL is mainly composed of forest (79.9%), but it is located on Mérida's outskirts which is experiencing rapid urban growth (Islebe et al., 2015). These findings reinforce that urban cover negatively influence community responses, even in landscapes with substantial forest cover, potentially driving biotic homogenization. This could explain the convergence of bat communities, where sensitive species are replaced by disturbance-adapted ones like *Artibeus jamaicensis*, *A. lituratus* and *Glossophaga mutica* (Avila-Cabadilla et al., 2012; Ramírez-Mejía et al., 2020). Indeed, *A. jamaicensis* and *G. mutica* were dominant species in human-modified landscapes, where the synanthropic rodent species *Mus musculus* and *Rattus rattus* were exclusively found.

Contrary to our expectations, forest cover was weakly related to the taxonomic diversity of both taxa. However, it was strongly and positively related to bat functional diversity, where specialized insectivorous bats that rely on dense vegetation were mostly found in landscapes with >47% forest cover. Indeed, forested landscapes in our study area harbored bat species with unique functional attributes, like gleaning and aerial feeding, specialist frugivores, sanguinivores, and with preferences

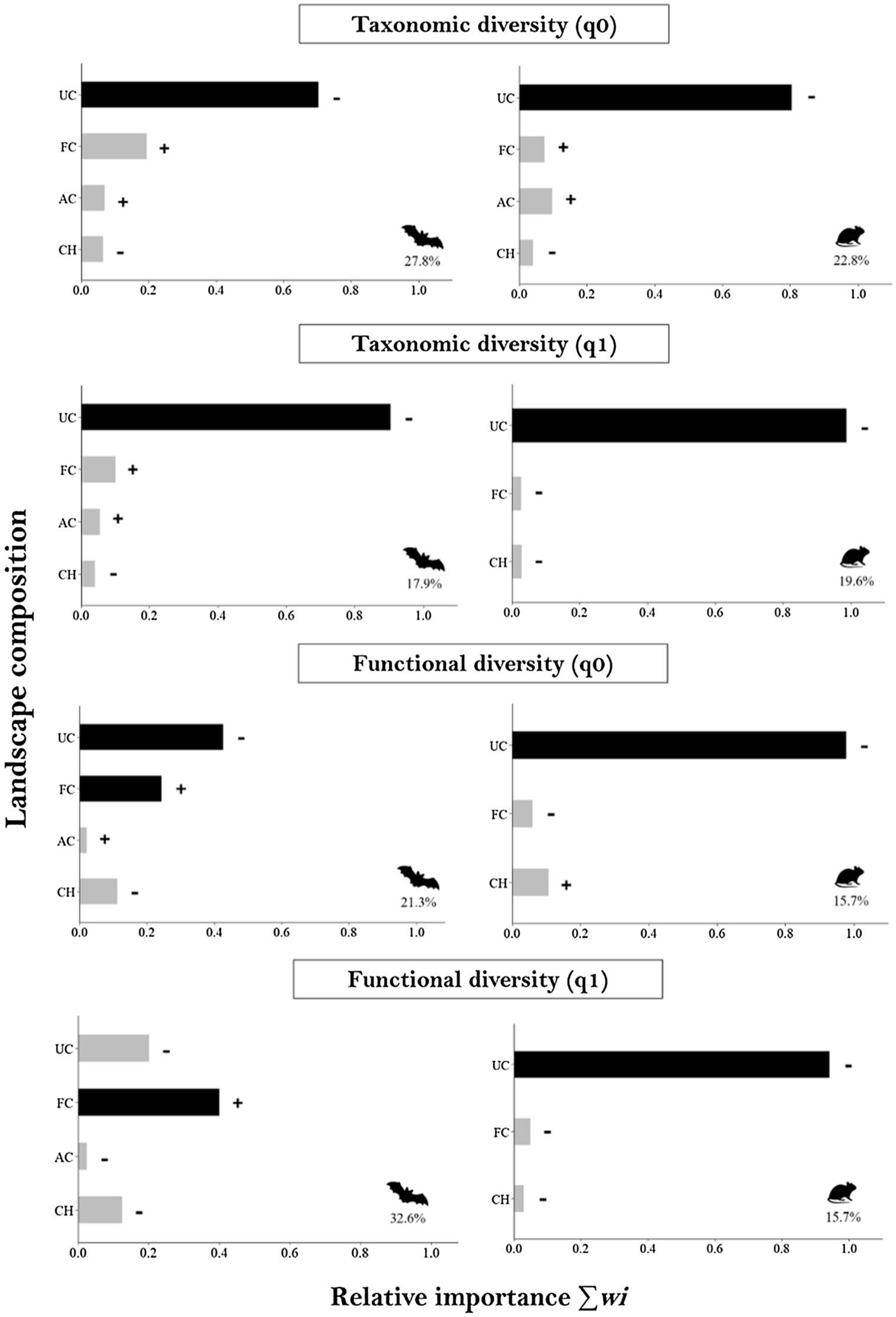

**Fig. 5.** Relative importance value (sum of Akaike weights *Σwi*) of each landscape compositional variable (UC: urban cover; FC: forest cover, AC: agriculture and cattle farming cover, CH: compositional heterogeneity) for predicting the taxonomic and functional diversity (Hill numbers of order 0 and 1) of bats and rodents. Black bars indicate predictor variables included in models within ΔAICc <2 of the best models; gray bars indicate variables that did not perform better than the null model. The sign (+/−) indicates if the response was positive or negative. The percentage of deviance explained by each complete model is also indicated. Diversity responses for rodents do not include AC results due to high collinearity with urban and forest cover. In all cases, each landscape variable was measured at their respective scales of effect (see scales in Table S6).

for specific tree strata (e.g., understory) (García-Morales et al., 2016; Ramírez-Mejía et al., 2020; Carvalho et al., 2021; Farneda et al., 2024). As forest cover provides a structurally complex environment with abundant roosting and feeding resources, our findings suggests that these attributes are favored in landscapes with higher forest cover. Also, some frugivorous bats that can forage in modified landscapes also depend on forest cover for feeding and roosting (Ripperger et al., 2015). Interestingly, the low and intermediate modified landscapes in Mérida exhibited low taxonomic and functional diversity despite having a relatively high forest cover. It is important to note that these landscapes are mainly composed of secondary forests. However, due to limitations in consistently distinguishing old-growth from secondary forests using satellite imagery, we combined them into a single forest class. While both provide key resources for bats and rodents, their ecological differences may influence species responses. For example, successional plants common in secondary forests, such as *Solanum* spp. and *Cecropia* spp, support generalist frugivores like *Artibeus* and *Carollia* (Carvalho et al., 2021; Saldaña-Vázquez et al., 2013). This pattern is reflected in our results on functional diversity for bats—specifically common and dominant species (q1 and q2)—where forest cover was the most important variable. The prevalence of successional vegetation in these secondary forests likely promotes higher abundances of generalist frugivores, even if overall diversity remains low.

Landscape compositional heterogeneity and agricultural cover had weak effects on bat and rodent diversity. A heterogeneous landscape matrix (i.e., secondary forest, scattered trees, arboreal crops) can provide supplementary resources, while also facilitating movement between forest remnants (Martínez-Ferreira et al., 2020). Therefore, it is important to assess not only landscape compositional heterogeneity but also local variables that reflect the heterogeneity of different land covers in the landscape (Avila-Cabadilla et al., 2012). On the other hand, we found that landscapes with specific land covers also differed in their most abundant species. For instance, *Sigmodon toltecus*, a generalist and disturbance-tolerant rodent commonly found in grasslands, crops and disturbed areas dominated the landscape with highest agricultural cover (TiI). In contrast, *Heteromys gaumeri*, a forest-associated granivore dominated the landscape with highest forest cover (CaL). These patterns may reflect differences in species and trait filtering driven by the land cover types that dominated each landscape (Paniccia et al., 2022).

It is known that changes in rodent and bat communities can disrupt food chains, seed dispersal, and insect control, affecting forest succession and ecological stability (Kunz et al., 2011; Morales-Díaz et al., 2019; Godó et al., 2022). The loss of these functions can also affect human well-being, disrupting species interactions and increasing the risk of emergence and transmission of infectious diseases (Sánchez-Soto et al., 2024). Taken together, our results indicate that human-mediated landscape modifications are a threat to different dimensions of diversity for both bats and rodents, even in landscapes with higher forest cover. Considering the negative role that urban cover plays on the taxonomic and functional diversity of both taxa, preserving biodiversity in the heterogeneous landscape mosaics of the Yucatán peninsula is a challenging task. Therefore, effective management strategies are needed to mitigate the negative impacts of human-landscape modification. Maintaining forest remnants and expanding overall native vegetation cover are crucial actions for increasing landscape connectivity and, consequently, species and communities' persistence. Other effective actions for biodiversity conservation in the Yucatán peninsula include reducing deforestation rates and establishing reserves both away from and connecting urban areas. Preventing deforestation is critical, especially for preserving bat and rodent assemblages and their key functions in forest ecosystems, including herbivory, predation, seed dispersal and pollination. Safeguarding these ecological processes supports ecosystem resilience and functionality, which are essential for sustaining biodiversity and the provision of ecosystem services within human-modified landscapes.

## Availability of data and material

All data produced from this study are provided in the manuscript and the electronic supplementary material.

## Declaration of competing interest

The authors declare that they have no conflict of interest.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.pecon.2025.09.004.

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