Received: 3 January 2025 | Revised: 11 May 2025 | Accepted: 25 May 2025

DOI: 10.1111/cobi.70108

Conservation Biology

CONTRIBUTED PAPER

Underrepresentation of bats in Africa's protected areas

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Article impact statement: Bats are underrepresented in African protected areas, particularly threatened and data deficient species with limited dispersal abilities.

Abstract

Biodiversity is severely threatened globally, with habitat loss and other human pressures accelerating species extinctions. Protected areas (PAs) are a critical conservation tool; however, their effectiveness in safeguarding many taxa, such as bats, remains unclear. Using georeferenced occurrence records and species distribution models (SDMs) for 263 sub-Saharan African bat species, we evaluated the coverage of bats in 7875 terrestrial PAs. Eighty-nine percent of bat species were recorded in at least 1 PA, yet 28 species, including 5 threatened and 15 data deficient species, were absent from all PAs. Species with large extents of occurrence were represented in more PAs, and fruit bats occupied significantly more PAs than clutter, edge, or open-air insectivorous foragers. The SDMs revealed high species richness in some undersurveyed areas, particularly in West and Central Africa and the Albertine Rift, emphasizing the need for targeted surveys. Our findings underscore critical data deficiencies related to bat conservation and stress the urgency of integrating bats into broader conservation planning. More surveys, enhanced data-sharing, and tailored conservation strategies are needed to improve bat representation in PAs and safeguard their ecological roles in Africa's biodiverse landscapes.

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KEYWORDS
bat conservation, biodiversity, Chiroptera, conservation planning, parks, threatened species

INTRODUCTION

Biodiversity worldwide is under severe threat from habitat loss, degradation, pollution, and climate change (IPBES, 2019; Tittensor et al., 2014; Wolkovich et al., 2014). These human-driven pressures, alongside many others, are putting countless species at risk, accelerating extinction rates, and undermining the stability and functioning of ecosystems globally (Cooke et al., 2023; Jantz et al., 2015; Pereira et al., 2024; Storch et al., 2022). Currently, over one fifth of known vertebrate species are threatened with extinction (Hoffmann et al., 2010; IUCN, 2024), including over a quarter of all mammal species (Cardillo et al., 2023; Sanders et al., 2024; Schipper et al., 2008). Africa, home to a vast array of unique ecosystems, is a refuge for numerous mammal species found nowhere else on Earth and plays a crucial role in preserving global biodiversity (Ceballos & Ehrlich, 2006; Turpie & Crowe, 1994; Visconti et al., 2011).

Protected areas (PAs) are a primary tool to mitigate biodiversity loss by safeguarding habitats from human impacts (Godet & Devictor, 2018). Globally, Target 3 of the Kunming–Montreal Global Biodiversity Framework—adopted by 196 countries in December 2022—aims to expand PAs to cover 30% of terrestrial, marine, and freshwater ecosystems by 2030 (CBD, 2022). However, economic pressures often undermine efforts to designate and manage PAs, leading to inadequate and uneven coverage across biomes and taxa (Oliveira et al., 2017; Symes et al., 2016; Watson et al., 2014). PAs in Africa cover over 4.3 million km^2 of natural habitat (UNEP-WCMC & IUCN, 2024), mostly renowned for their large, charismatic mammals (Craigie et al., 2010; Western et al., 2009). However, the efficacy of the African PA network has not yet been assessed at a continental scale for the majority of low-profile and smaller-bodied mammals (Rodrigues et al., 2004).

For many taxa, which species are present in PAs is yet to be determined, even though this is essential for conservation planning and is often used as a metric to evaluate PA effectiveness (Jennings, 2000; Van Breugel et al., 2015). Despite being the second-most diverse group of mammals in the world, with 266 species recorded in sub-Saharan Africa alone (Monadjem, Montauban, et al., 2024), bats (Mammalia: Chiroptera) are often excluded from biodiversity assessments, and significant gaps remain in understanding how well they are represented in PAs. At a local scale, bats are frequently the most species-rich group of mammals in Africa, especially in savanna and forest habitats at elevations below 1500 m asl (Monadjem, Farooq, et al., 2024). Bats occupy a variety of habitats and can be broadly classified into 4 foraging assemblages based on their diet and foraging style: clutter, edge, and open-air foragers (insectivorous species) and fruit bats (Monadjem, Farooq, et al., 2024). In addition to their diversity, bats deliver critical ecosystem services, such as pest control and seed dispersal (Aziz et al., 2021; Kunz et al., 2011; Tuneu-Corral et al., 2023). Furthermore, they also exhibit varying levels of sensitivity to disturbance (Cleary et al., 2016; Kingston et al., 2003; Struebig et al., 2010), making them valuable bioindicators (Jones et al., 2009) that can provide nuanced insights into the effectiveness of PAs. However, bats remain poorly studied, and despite their ecological importance, they are rarely prioritized in conservation management or policy (Frick et al., 2020) and are frequently subjected to persecution (Kingston, 2016; Rocha et al., 2021).

Bats are poorly known partly because they are difficult to observe and identify without capture (Meyer et al., 2011; Tanshi et al., 2021) and have high levels of cryptic unresolved diversity (Baldwin et al., 2021; Demos et al., 2019; Monadjem, Guyton, et al., 2020; Patterson et al., 2024). Additionally, the difficulty of capturing different species varies considerably. Some bat families are frequently trapped across habitats (e.g., Pteropodidae), whereas others (e.g., Molossidae) forage above forest canopies and in open spaces, where they are difficult to catch or are more adept at avoiding capture (e.g., clutter foragers in the families Vespertilionidae, Rhinolophidae, and Hipposideridae) (Mande et al., 2023; Monadjem, Farooq, et al., 2024). These limitations result in incomplete occurrence records and poorly defined distributional ranges. Species distribution models (SDMs) help address these uncertainties by predicting bat distributions based on known occurrence points (Cooper-Bohannon et al., 2016; Herkt et al., 2016; Razgour et al., 2016). Efforts to overcome this shortfall in knowledge of African bat distributions include the recently published African bat database (Monadjem, Montauban, et al., 2024)—a curated set of unique locality records of all bat species in sub-Saharan Africa—and Maxent-based SDMs.

We used georeferenced distributional data and models from the African bat database to evaluate the effectiveness of the existing PA network of mainland Africa in conserving sub-Saharan bat species. In particular, we aimed to examine the coverage of species represented in PAs; identify species that have not been recorded in any PA; assess the coverage of species in PAs based on their family, extent of occurrence (EOO), extinction risk, and foraging assemblage; and compare whether using SDMs instead of actual occurrence records leads to different representation of bats in the PA network. We hypothesized that species with large geographic ranges intersect more PAs than species with small ranges, making range size the most important ecological correlate of the number of PAs in which a bat species occurs. We also hypothesized that due to their larger home range sizes (Wood et al., 2024), fruit bats and open-air foragers are recorded more often in PAs than edge or clutter foragers and that threatened bat species are recorded in the fewest PAs due to their often-restricted ranges and small population sizes.

METHODS

Data

We used bat species occurrence records, SDMs, and EOO (i.e., the area within the shortest continuous boundary that includes all known, inferred, or projected sites of a species' current occurrence) from the African bat database (Monadjem, Montauban, et al., 2024). Maxent models were used by Monadjem, Montauban, et al. (2024) to develop SDMs for African bat species, run at a resolution of 2.5 arc minutes with BIOCLIM variables and elevation data from the WorldClim database (Hijmans et al., 2005). The Maxent models were run with the dismo R package (Hijmans et al., 2010), and detailed descriptions of the model testing and evaluation are in Monadjem, Montauban, et al. (2024).

We cropped records from the African bat database to mainland sub-Saharan Africa only (excluding islands and north Africa above latitude 22°N). This retained 16907 unique locality records of 263 species (of the initial 266 species) from 12 families and 52 genera from sub-Saharan Africa. Records covered all biomes and ranged in elevation from sea level up to 4207 m asl. We followed the taxonomy of Simmons and Cirranello (2025) and included the 16 taxa from the African bat database for which a specific species identity could not be assigned (i.e., species whose epithets begin with "cf." followed by the name of the taxon closest in morphology). Maxent-based SDMs were available for 208 species, and EOO was available for 238 species (Monadjem, Montauban, et al., 2024).

We compiled the conservation status of bats from the International Union for Conservation of Nature (IUCN) Red List (IUCN, 2024) and matched it to the most recent taxonomy with the Bat Taxonomy Alignment Tool (Sherman et al., 2023). Threatened species adhere to the IUCN definitions and were classified as vulnerable (VU), endangered (EN), and critically endangered (CR). Nonthreatened categories included least concern (LC) and near threatened (NT). Species listed as data deficient (DD) and not evaluated (NE) lack proper assessments of their extinction risk. We extracted the foraging assemblage of each bat species from Monadjem, Farooq, et al. (2024) and filled the assemblage of any missing taxa based on that of other species in the genus.

We downloaded shapefiles for PAs from the December 2024 version of the World Database of Protected Areas (WDPA) (UNEP-WCMC & IUCN, 2024). The dataset includes PAs of all 7 IUCN PA management categories and all governance types—including federal PAs, privately owned areas, and Indigenous and local community-based PAs. We filtered the dataset to retain only terrestrial PAs and incorporated both polygon and point data. Around 9% of WDPA spatial information was available only as point data (i.e., records lacking a defined boundary), and their inclusion enabled a more robust analysis when conducting a gap analysis for a given taxon (UNEP-WCMC & IUCN, 2024). As recommended in the WDPA manual, we incorporated point data by creating a zone around the point with a radius proportional to the reported total area of the PA (UNEP-WCMC & IUCN, 2024). We excluded point records for which area was not reported. All shapefiles were cropped to mainland sub-Saharan Africa only (excluding islands and north Africa above latitude 22°N). The extent of the study area, PAs, and bat records are shown in Figure 1.

Data analyses

All data analyses and mapping were done in R software (R Core Team, 2022). We used the overlay between occurrence records and PAs to calculate the number of PAs in which each species occurred and to identify bat species that were not recorded in any PAs. This was done by extracting occurrence records from the African bat database and overlaying them with the PA shapefile to extract records in PAs with the extract function in the terra R package (Hijmans et al., 2024).

To visualize the taxonomic coverage of bats in PAs, we plotted the number of PAs in which each species occurred on a phylogram with the ggtree R package (Yu et al., 2017). The backbone phylogenetic tree was adapted from Upham et al. (2019) with sequences of closely related species in the case of missing taxa and processed using the ape and phytools R packages (Paradis & Schliep, 2019; Revell, 2024). To assess differences in the representation of bat families in PAs, we compared the median number of PAs in which species of different bat families occurred with a Kruskal–Wallis test. This nonparametric test was selected because the data did not meet the assumptions of normality required for parametric alternatives.

We examined the coverage of bat species in PAs by modeling the total number of PAs each bat species occurred in (response variable) as a function of 3 explanatory variables: the species' EOO (continuous variable), IUCN Red List category (7 categories), and foraging assemblage (4 categories). We fitted a generalized linear model with quasi-Poisson distribution with the glm function from the stats R package (R Core Team, 2022). This model was selected to deal with overdispersion in the response variable count data. Model outputs were examined to assess the significance of each predictor in explaining variation in PA coverage among bat species.

To visualize the distribution and coverage of threatened (i.e., CR, EN, VU), DD, and NE bat species across sub-Saharan Africa, we created a bivariate map showing conservation status in 2 categories (DD or NE species and threatened species), following an approach similar to that of Fernández-Llamazares et al. (2021). We grouped PAs into 3 categories based on the number of bat species they contained. For threatened species, groups included PAs with 0 threatened species, 1–2 threatened species, and ≥3 threatened species. For the combined sum of DD and NE species, we grouped PAs into 3 categories: ≤2 DD–NE species, 3–5 DD–NE species, and ≥6 DD–NE species.

To determine whether using SDMs instead of actual occurrence records leads to different representation of bats in the PA network, we mapped species richness in PAs based on actual occurrence records and predicted records. The predicted

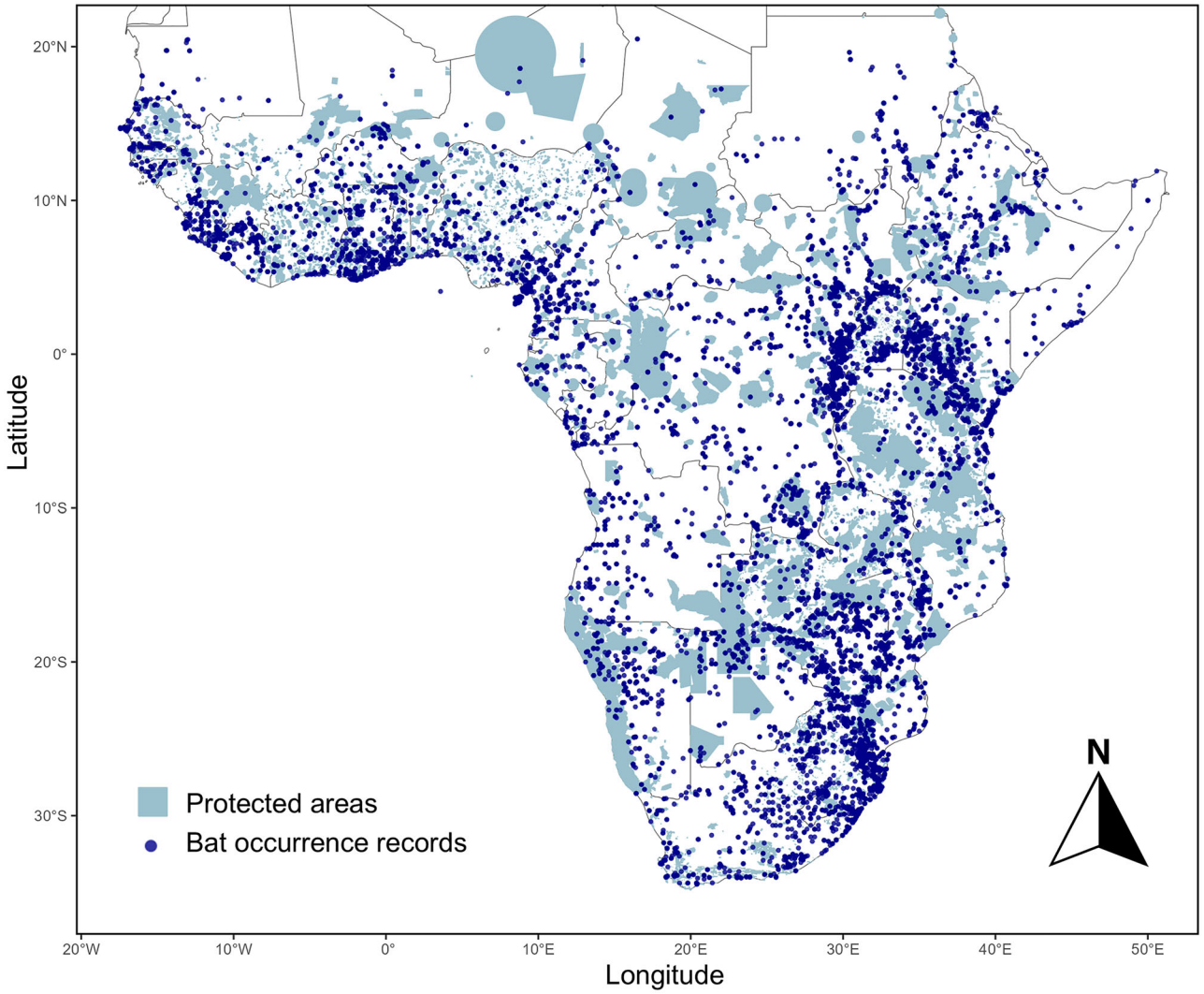

FIGURE 1 Sub-Saharan African protected areas ($n = 7875$) and bat occurrence records ($n = 16907$) of the 263 sub-Saharan bat species. Protected areas are from the December 2024 version of the World Database on Protected Areas layer (UNEP-WCMC & IUCN, 2024), and occurrence records were extracted from the African bat database (Monadjem, Montauban, et al., 2024).

species richness was calculated by overlaying the SDMs (instead of occurrence records) of each bat species with the PA shapefile to extract records in PAs.

RESULTS

A total of 16907 bat records were overlaid with 7875 PAs in mainland sub-Saharan Africa (Figure 1). Bats were recorded in 855 of 7875 PAs (Appendix S1). There was a mean of 6.0 species per PA based on actual occurrence records. Based on actual occurrence records, 235 (89%) bat species were present in at least 1 PA. The number of PAs in which each bat species was recorded ranged from 0 to 174 (median = 9.0) (Figure 2a; Appendix S2). Twenty-eight species from 7 families were not recorded in any PAs (Table 1), and 21 species occurred in just 1 PA. Three species stood out for being present in many PAs. *Afronycteris nana* (vespertilionid edge forager) and *Nycteris thebaica* (nycterid clutter forager) were both in 174 PAs. *Mops pumilus* (molossid open-air forager) was in 154 PAs (Figure 2a,b; Appendix S2).

The median number of PAs in which a species occurred was significantly different among bat families ($\chi^2 = 57.93$, df = 11, $p < 0.001$). It was lowest for Rhinopomatidae and Rhinolophidae (3.0 and 3.5 PAs, respectively) and highest for Pteropodidae and Megadermatidae (22.0 and 54.5 PAs, respectively) (Figure 2b).

All explanatory variables had a significant effect on the number of PAs in which a species occurred: EOO (glm, $F = 399.8$, df = 1, $p < 0.001$), IUCN Red list category (glm, $F = 2.4$, df = 6, $p < 0.05$), and foraging assemblage (glm, $F = 5.4$, df = 3, $p < 0.01$). Generally, the larger the EOO of a species, the more PAs the species was recorded in (Figure 3a). Threatened bat species occurred in low numbers of PAs (Figure 3a,b). The num-

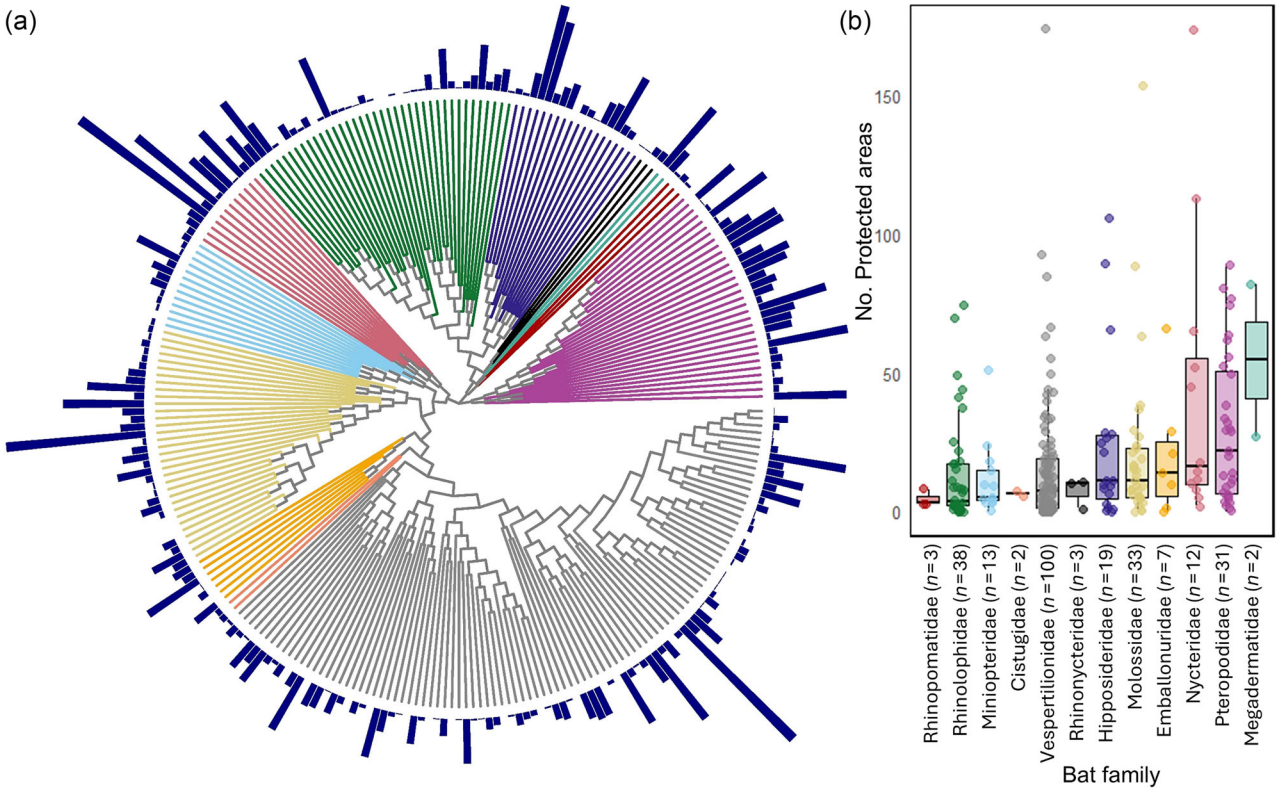

FIGURE 2 Taxonomic representation of bats in protected areas: (a) number of protected areas in which each of the 263 sub-Saharan Africa bat species occurs (dark blue bars) mapped onto their phylogenetic tree (branches color-coded by family) and (b) number of protected areas in which the species in each family occur.

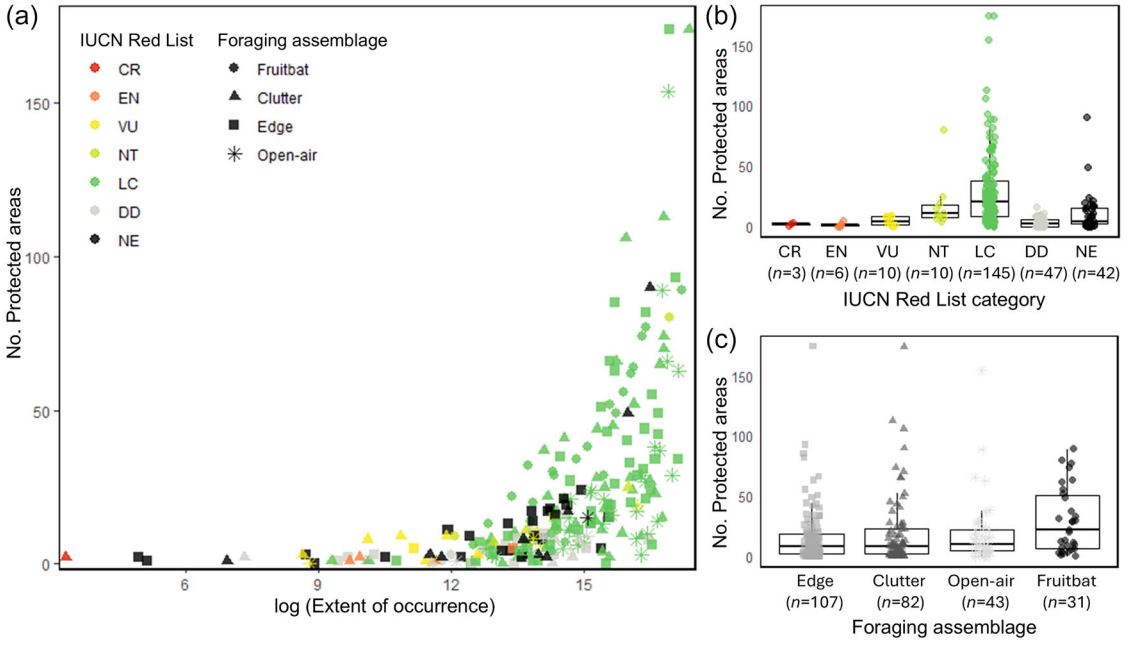

FIGURE 3 Relationship between extent of occurrence, International Union for Conservation of Nature (IUCN) Red List category and foraging assemblage of species, and their protected area coverage: (a) extent of occurrence (log-transformed) relative to the number of protected areas each species occurs in (IUCN categories defined in Table 1), (b) number of protected areas in which the species in each IUCN Red List category occurs, and (c) number of protected areas in which the species in each foraging assemblage occur.

TABLE 1 The 28 species of sub-Saharan African bats ($n = 263$) not recorded in any protected area.

Family	Species	IUCN Red List category	Foraging assemblage
Emballonuridae	*Taphozous hildegardeae*	VU	Open air
Hipposideridae	*Asellia italosomalica*	DD	Clutter
Hipposideridae	*Hipposideros megalotis*	LC	Clutter
Miniopteridae	*Miniopterus minor*	DD	Edge
Molossidae	*Mops gallagheri*	DD	Open air
Molossidae	*Mops niangarae*	DD	Open air
Molossidae	*Mops petersoni*	VU	Open air
Pteropodidae	*Epomophorus grandis*	DD	Fruit bat
Rhinolophidae	*Rhinolophus adami*	DD	Clutter
Rhinolophidae	*Rhinolophus mabuensis*	EN	Clutter
Rhinolophidae	*Rhinolophus sakejiensis*	DD	Clutter
Rhinolophidae	*Rhinolophus silvestris*	DD	Clutter
Rhinolophidae	*Rhinolophus willardi*	EN	Clutter
Vespertilionidae	*Barbastella leucomelas*	LC	Edge
Vespertilionidae	*Cnephaeus platyops*	DD	Edge
Vespertilionidae	*Glauconycteris atra*	NE	Edge
Vespertilionidae	*Glauconycteris kenyacola*	DD	Edge
Vespertilionidae	*Hypsugo ariel*	DD	Edge
Vespertilionidae	*Kerivoula eriophora*	DD	Clutter
Vespertilionidae	*Myotis dieteri*	DD	Edge
Vespertilionidae	*Myotis nimbaensis*	CR	Edge
Vespertilionidae	*Nycticeinops* cf. *grandidieri*	NE	Edge
Vespertilionidae	*Nycticeinops* cf. *macrocephalus*	NE	Edge
Vespertilionidae	*Pipistrellus kuhlii*	LC	Edge
Vespertilionidae	*Pipistrellus permixtus*	DD	Edge
Vespertilionidae	*Plecotus christii*	DD	Clutter
Vespertilionidae	*Scotophilus* cf. *andrewreborii*	NE	Edge
Vespertilionidae	*Scotophilus* cf. *dinganii*	NE	Edge

Abbreviations: CR, critically endangered; DD, data deficient; EN, endangered; IUCN, International Union for Conservation of Nature; LC, least concern; NE, not evaluated; NT, near threatened; VU, vulnerable.

ber of PAs occupied by fruit bat species was significantly higher than that of species of other foraging assemblages, and it was higher for clutter foragers than for open-air foragers (Figure 3c; Appendix S3).

The distribution of threatened and DD–NE bat species in PAs based on actual occurrence records did not show any clustering in sub-Saharan Africa (Figure 4). Massif du Ziama Forest (Guinea) and Mount Nimba (Guinea—Ivory Coast) had the most threatened and DD–NE bat species. Many other PAs had high numbers of DD–NE bat species, including Taï National Park and Comoé National Park (Ivory Coast), Kruger National Park (South Africa), Upemba National Park (Democratic Republic of the Congo), Tsavo West National Park (Kenya), and Budongo National Park (Uganda). The predicted PAs harboring higher numbers of threatened bats based on SDMs were in the upland regions of West Africa, especially the Liberia–Guinea border zone, tropical Cameroon, the Albertine Rift, and parts of Ethiopia, Kenya, Tanzania, and northeastern South Africa.

Of the 19 threatened bat species analyzed, 5 were not recorded in any PA, 3 were recorded in a single PA, and the rest were recorded in 2–9 PAs (Appendix S2). Of the 47 DD bats in sub-Saharan Africa, 15 were not present in any PA and 7 were in just 1 PA (Appendix S2). The remainder of the DD species were present in 2–16 PAs. Finally, of the 42 NE species, 5 were not recorded in any PA, 4 were present in a single PA, and the rest occurred in 2–90 PAs (Appendix S2).

Species richness in PAs did not show any clear geographical pattern; species-rich PAs were scattered throughout the continent (Figure 5a). Comoé National Park (Ivory Coast), Budongo National Park (Uganda), and Greater Kruger National Park (South Africa) had the highest bat species richness (54, 51, and 46 species, respectively). In contrast, the species richness of PAs based on the Maxent-based SDMs predicted high species richness in specific regions of Central and West Africa, the Albertine and Gregory Rifts in East Africa, and central Mozambique (Figure 5b). The comparative number of bat species in PAs based on SDMs was far greater. Only 4 of the 208 species (1.9%) were predicted to not occur in PAs, and 35 species were predicted to occur in 1000 or more PAs (Appendix S2). The discrepancy between these 2 maps in Figure 5 is not surprising considering the large number of PAs that have yet to be surveyed for bats (Appendix S1).

DISCUSSION

Our work is the first spatial analysis of the conservation status of sub-Saharan African bats based on curated bat records. Our results highlight that, although 89% of bat species occur in at least 1 PA, the distribution of species is uneven across PAs. Some species were absent or poorly represented. Five threatened species, 15 DD species, and 5 NE species were absent from all PAs, underscoring critical gaps in conservation coverage. Moreover, the discrepancies between actual and predicted richness underscore the urgent need for comprehensive surveys to better inform conservation priorities.

The absence of 28 species from the PA network can be explained by multiple factors. Many species (e.g., *Pipistrellus permixtus*, *Glauconycteris kenyacola*, and *Mops gallagheri*) are only known from a type locality (Van Cakenberghe & Seamark, 2023) that is not in a PA. These species are so poorly known that nothing further can be said about their distributional ranges, let alone why they are absent from PAs. Some species, such as *P. permixtus*, also remain taxonomic mysteries; their phylogenetic relationships with congenerics are unclear (Monadjem et al., 2021). Others, such as *Miniopterus nimbae*, *Myotis nimbaensis*, *Rhinolophus namuli*, and *Pseudoromicia mbamminkom*, have been described only recently (Curran et al., 2022; Grunwald et al., 2023; Monadjem et al., 2019; Simmons et al., 2021) and need more sampling to determine their full distributional ranges. For at least a few of

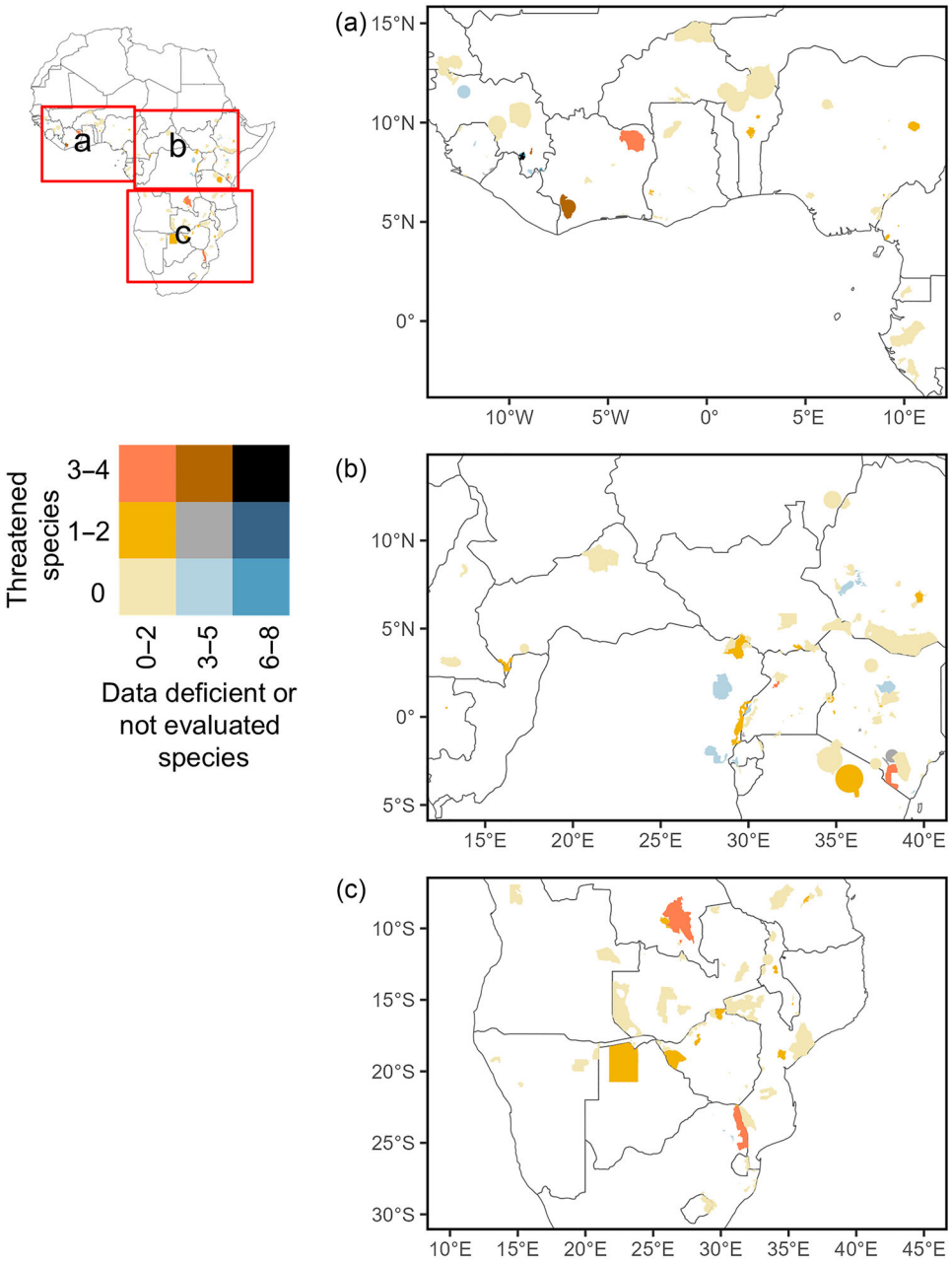

FIGURE 4 Protected areas harboring bat species classified as threatened, data deficient, and not evaluated under the International Union for Conservation of Nature Red List across 3 areas (a–c) in sub-Saharan Africa and a bivariate map of the number of threatened (vulnerable, endangered, and critically endangered) bat species in protected areas versus the combined number of data-deficient and not-evaluated bat species in protected areas across sub-Saharan Africa.

the 28 species, we suspect that their habitat does not occur in any PAs. This is particularly obvious for the arid zone of the Horn of Africa, where PA locations are not included in the WDPA but where at least 2 species that are not found in PAs (i.e., *Hipposideros megalotis* and *Asellia italosomalica*) are known to occur.

Species with large EOOs were recorded in more PAs, supporting our prediction that broader distributions lead to higher PA representation. This is in line with results of other studies (e.g., Pessoa Da Silva & De Marco Júnior, 2023). The geographic range of a species is part of the IUCN Red List criteria, which include whether the EOO is based on few occurrence records or whether the population has fluctuated or declined (IUCN, 2024). Therefore, it is unsurprising that many threatened species have small EOOs or lack an EOO estimation altogether due to limited records. Nonetheless, the lack of overlap between their distributions and PAs could be detrimental for the conservation of these species, particularly because natural habitats are increasingly threatened (Frick et al., 2020).

Fruit bats (Pteropodidae) occurred in significantly more PAs than all insectivorous foraging assemblages. Most pteropodids have generalist feeding habits, strong dispersal capabilities, and

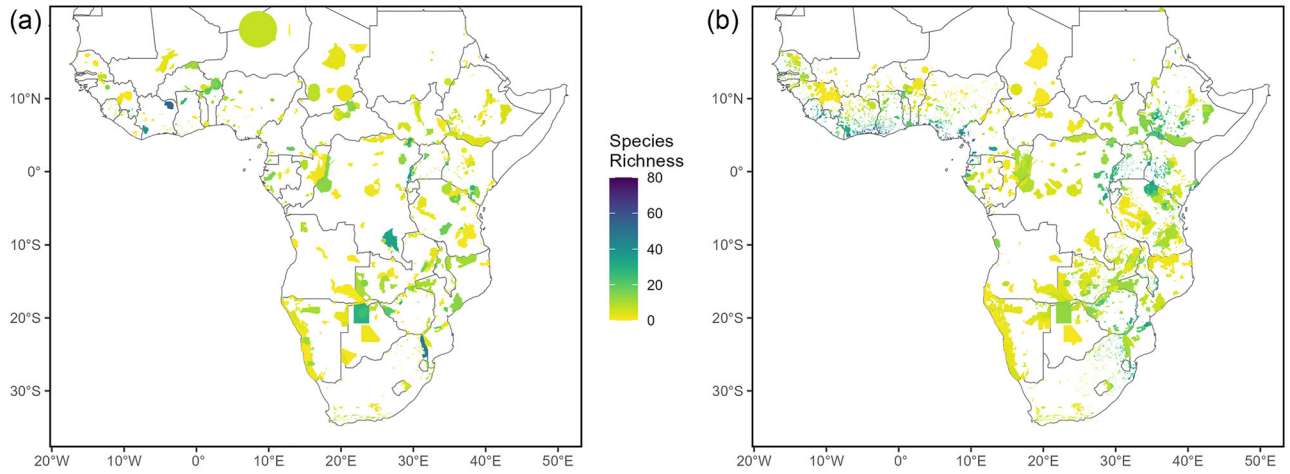

FIGURE 5 Number of bat species in protected areas in sub-Saharan Africa based on (a) occurrence records and (b) species distribution models.

large home ranges. These characteristics allow them to use resources in a broad range of habitats, including disturbed landscapes (Egert-Berg et al., 2021; Meijaard et al., 2005; Wood et al., 2024). This, along with their ease of capture, large size, and high visibility when roosting in trees, even in urban areas, likely contributed to more occurrence records and therefore higher representation in PAs. The comparative underrepresentation of insectivorous bats in PAs raises concern; the lack of protection of these species jeopardizes their conservation and the vulnerability of the pest-suppression services they provide (Tuneu-Corral et al., 2023). Among insectivorous foraging assemblages, differences were not significant, except between clutter foragers and open-air foragers, with the former being represented in more PAs. Because clutter species mostly forage in forest interior habitats, this may be explained by the amount of PAs that are forested and the difficulty in surveying open-air foragers (García et al., 2024; Struebig et al., 2010).

Our prediction that threatened species are underrepresented in PAs was supported and is consistent with the results of similar studies (Beresford et al., 2011; Venter et al., 2014). Of the 19 sub-Saharan bat species classified as threatened, almost half were present in only 1 PA or no PAs, whereas the rest were found in fewer than 10 PAs. That 22 of the 47 DD species were recorded in at most 1 PA is also a cause for concern, particularly because the majority of DD species may in fact be threatened (Borgelt et al., 2022). Predicted species richness from SDMs suggests many unsurveyed PAs may host additional bat species, including threatened and DD species. PAs predicted to host high species richness included those in the upper and lower Guinean forests, the Congolian rainforest, central Mozambique, and the equatorial range of Eastern Africa. Species in these areas are currently underrecorded, and attention is needed to accurately assess their extinction risk, particularly for those still lacking an initial IUCN Red List evaluation, as a stepping stone to ensuring their conservation.

Our results showed a clear discrepancy in species richness of PAs based on actual occurrence records and predicted presence from SDMs, likely due to uneven and biased sampling (Fisher-Phelps et al., 2017; Tanshi & Kingston, 2021). As with other similar studies (e.g., Struebig et al., 2010), use of predicted distributions improved the overall representation of bat species in PAs compared with use of actual species records. Predicted richness patterns in PAs align with estimated continental richness patterns (Herkt et al., 2016) but reflect substantial gaps in survey coverage. Bat surveys are heavily biased toward southern Africa (Monadjem, Taylor, et al., 2020), with large areas of tropical Africa still undersampled (Monadjem, Montauban, et al., 2024). This bias is evident in maps of actual records. Bat diversity hotspots, such as Kruger National Park (Rautenbach, 1982) and Comoé National Park (Fahr & Kalko, 2011), reflected sites with extensive survey efforts, whereas PAs in the Albertine Rift such as Virunga National Park (DRC) were underrepresented in bat research. Some occurrence records may not appear in SDMs due to limitations in species distribution modeling, particularly for microendemics, small sample sizes, or inaccurate environmental covariates (Synes & Osborne, 2011; Van Proosdij et al., 2016; Wisz et al., 2008). Acknowledging these discrepancies and biases underscores the urgent need for targeted surveys in less well-sampled regions to improve bat biodiversity assessments. However, there will also be a need to create new PAs to conserve some of the bat species absent from the current PA network.

Despite being the most extensive worldwide database on PAs, the WDPA is still a dynamic dataset that remains incomplete. Some countries, such as Somalia, have not contributed spatial information (UNEP-WCMC & IUCN, 2024). The IUCN's assessments also face challenges for inconspicuous species, such as bats, for which limited knowledge of population trends, abundance, and distribution often results in underestimated extinction risks (Edgar, 2025). Research and conservation efforts are hampered by severe data deficiencies, particularly in regions where bat diversity is highest but resources for their study and protection remain scarce. Many regions and taxa remain severely undersampled or are hindered by unresolved taxonomies, highlighting the urgent need for more targeted surveys and the submission of data to collaborative efforts like the African bat database (Monadjem, Montauban, et al., 2024).

Without fundamental knowledge of species distributions, the ability to implement effective conservation strategies is severely hampered.

Conservation implications

Our findings highlight the urgent need to integrate bat conservation more explicitly into PA management and expansion strategies across Africa. The lack of foundational data and the underrepresentation of many bat species in PAs, coupled with increasing threats from habitat loss, climate change, and roost disturbance (Frick et al., 2020), underscore the necessity of evidence-based conservation planning that considers bats alongside other biodiversity priorities (Berthinussen et al., 2019; Sutherland et al., 2019).

PAs are often assumed to be safe havens for wild animals, but for many species this relationship has not yet been clearly established. The management of many African PAs is tailored to large, charismatic megafauna, which tend to be the central focus of ecotourism (Monadjem & Unwin, 2023). The proliferation of large megafauna may not always go hand in hand with populations of smaller vertebrates (McCleery et al., 2018). Species coexistence can have complex effects that influence whether specific PAs are viable structures for bat conservation. For example, savanna regions where PAs support large elephant populations may be detrimental to bats (Fenton et al., 1998; Parker & Bernard, 2023), whereas megaherbivores at lower densities in PAs in desert ecosystems may increase bat species richness and activity (Laverty & Berger, 2022). In general, PAs are a valuable conservation tool because they protect roosting sites (such as caves, crevices, and trees) and help maintain the ecosystem services provided by the bat populations that inhabit them (Cooper-Bohannon et al., 2016; Tuneu-Corral et al., 2025).

Deforestation and habitat loss remain one of the most pressing threats to bat diversity across the continent, driven largely by the expansion of small-scale croplands and commodity crops (e.g., cacao, oil palm, rubber, and cashew nuts) (Masolele et al., 2024; Tyukavina et al., 2018). Urbanization poses another major threat because it leads to rapid transformation of natural habitats (Liu et al., 2016). Although some bat species can adapt to anthropogenic landscapes, many lose critical roosting and foraging sites (Frick et al., 2020; Russo & Ancillotto, 2015). Many bat species rely on continuous tree cover and cannot persist in fragmented landscapes (Meyer et al., 2016). PAs with well-managed buffer zones and corridors can help maintain connectivity and reduce the impacts of habitat loss, particularly if the requirements of diverse types of taxa are considered in PA designation and planning (Ducci et al., 2019). Specific measures could include strict protection of forest fragments and riparian zones, as well as the identification and enhancement of key bat foraging areas in PAs.

Roost disturbance is another major concern, particularly for cave-roosting bat species, which face threats from tourism, mining, hunting, and guano harvesting (Tanalgo & Hughes, 2025; Tanalgo et al., 2022). Implementing seasonal access restrictions, formal protection for critical roost sites, and sustainable guano harvesting practices would reduce disturbance and improve conservation outcomes. Similarly, hunting pressure on fruit bats for bushmeat and traditional medicine remains widespread (Mickleburgh et al., 2009; Mildenstein et al., 2016; Tackett et al., 2022). Tanalgo et al. (2023) found that higher numbers of bat species are hunted in countries with low PA coverage, suggesting that strong PA enforcement is needed to prevent illegal harvesting in reserves.

Our study represents the first attempt to understand the representation of sub-Saharan African bat species in PAs and underscores the need for targeted conservation actions. We emphasize the urgent need for robust species inventories as a key step in integrating bats into PA planning and management, particularly in areas where undersampling and taxonomic uncertainties are hindering understanding of bat distributions and the requirements needed to conserve them. Future efforts should focus on integrating bats into PA conservation policies, strengthening monitoring programs, and promoting data sharing to enhance conservation efforts across the continent.

ACKNOWLEDGMENTS

We thank all data contributors to the first version of the African bat database on which this study is based. We particularly acknowledge the initial massive effort of F.P.D. Cotterill who, alongside A.M. and P.J.T, compiled and curated the records of the 2 editions of the Bats of Southern and Central Africa book that were the starting point for the African bat database. This growing resource is a collaborative effort that will only strengthen as more researchers contribute to it in coming years, which we openly encourage, to jointly improve research and conservation efforts focused on African bats. We also acknowledge the funding and institutional support of Global South Bats and National Geographic for hosting in-person meetings that included C.M., A.M., P.W.W., and E.B.F. and played an important role in conceptualizing this work. We thank V. Jovanović for his help with statistical analyses. C.M. was supported through the Imperial College London President's PhD Scholarship. We also thank the reviewers and handling editors for their valuable suggestions, which greatly improved this manuscript.

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REFERENCES

Aziz, S. A., McConkey, K. R., Tanalgo, K., Sritongchuay, T., Low, M.-R., Yong, J. Y., Mildenstein, T. L., Nuevo-Diego, C. E., Lim, V.-C., & Racey, P. A. (2021). The critical importance of Old World fruit bats for healthy ecosystems and economies. *Frontiers in Ecology and Evolution*, *9*, Article 641411.

Baldwin, H. J., Vallo, P., Ruiz, A. T., Anti, P., Nkrumah, E. E., Badu, E. K., Oppong, S. K., Kalko, E. K. V., Tschapka, M., & Stow, A. J. (2021). Concordant patterns of genetic, acoustic, and morphological divergence in the West African Old World leaf-nosed bats of the Hipposideros caffer complex. *Journal of Zoological Systematics and Evolutionary Research*, *59*, 1390–1407.

Beresford, A. E., Buchanan, G. M., Donald, P. F., Butchart, S. H. M., Fishpool, L. D. C., & Rondinini, C. (2011). Poor overlap between the distribution of Protected Areas and globally threatened birds in Africa. *Animal Conservation*, *14*, 99–107.

Berthinussen, A., Richardson, O. C., & Altringham, J. D. (2019). *Bat conservation: Global evidence for the effects of interventions*. University of Cambridge.

Borgelt, J., Dorber, M., Høiberg, M. A., & Verones, F. (2022). More than half of data deficient species predicted to be threatened by extinction. *Communications Biology*, *5*, Article 679.

Cardillo, M., Skeels, A., & Dinnage, R. (2023). Priorities for conserving the world's terrestrial mammals based on over-the-horizon extinction risk. *Current Biology*, *33*, 1381.e6–1388.e6.

Ceballos, G., & Ehrlich, P. R. (2006). Global mammal distributions, biodiversity hotspots, and conservation. *Proceedings of the National Academy of Sciences of the United States of America*, *103*, 19374–19379.

Cleary, K. A., Waits, L. P., & Finegan, B. (2016). Agricultural intensification alters bat assemblage composition and abundance in a dynamic Neotropical landscape. *Biotropica*, *48*, 667–676.

Convention on Biological Diversity (CBD). (2022). *Decision adopted by the Conference of the Parties to the Convention on Biological Diversity 15/4. Kunming-Montreal Global Biodiversity Framework*. https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf

Cooke, R., Sayol, F., Andermann, T., Blackburn, T. M., Steinbauer, M. J., Antonelli, A., & Faurby, S. (2023). Undiscovered bird extinctions obscure the true magnitude of human-driven extinction waves. *Nature Communications*, *14*, Article 8116.

Cooper-Bohannon, R., Rebelo, H., Jones, G., Cotterill, F. W., Monadjem, A., Schoeman, M. C., Taylor, P., & Park, K. (2016). Predicting bat distributions and diversity hotspots in Southern Africa. *Hystrix, Italian Journal of Mammalogy*, *27*, 38–48.

Craigie, I. D., Baillie, J. E. M., Balmford, A., Carbone, C., Collen, B., Green, R. E., & Hutton, J. M. (2010). Large mammal population declines in Africa's protected areas. *Biological Conservation*, *143*, 2221–2228.

Curran, M., Kopp, M., Ruedi, M., & Bayliss, J. (2022). A new species of horseshoe bat (Chiroptera: Rhinolophidae) from Mount Namuli, Mozambique. *Acta Chiropterologica*, *24*, 19–40.

Demos, T. C., Webala, P. W., Kerbis Peterhans, J. C., Goodman, S. M., Bartonjo, M., & Patterson, B. D. (2019). Molecular phylogenetics of slit-faced bats (Chiroptera: Nycteridae) reveal deeply divergent African lineages. *Journal of Zoological Systematics and Evolutionary Research*, *57*, 1019–1038.

Ducci, L., Roscioni, F., Carranza, M. L., Agnelli, P., Russo, D., Frate, L., Loy, A., Santini, G., & Di Febbraro, M. (2019). The role of protected areas in preserving habitat and functional connectivity for mobile flying vertebrates: The common noctule bat (*Nyctalus noctula*) in Tuscany (Italy) as a case study. *Biodiversity and Conservation*, *28*, 1569–1592.

Edgar, G. J. (2025). IUCN Red List criteria fail to recognise most threatened and extinct species. *Biological Conservation*, *301*, Article 110880.

Egert-Berg, K., Handel, M., Goldshtein, A., Eitan, O., Borissov, I., & Yovel, Y. (2021). Fruit bats adjust their foraging strategies to urban environments to diversify their diet. *BMC Biology*, *19*, Article 123.

Fahr, J., & Kalko, E. K. V. (2011). Biome transitions as centres of diversity: Habitat heterogeneity and diversity patterns of West African bat assemblages across spatial scales. *Ecography*, *34*, 177–195.

Fenton, M. B., Cumming, D. H. M., Rautenbach, I. L., Cumming, G. S., Cumming, M. S., Ford, G., Taylor, R. D., Dunlop, J., Hovorka, M. D., Johnston, D. S., Portfors, C. V., Kalcounis, M. C., & Mahlanga, Z. (1998). Bats and the loss of tree canopy in African woodlands. *Conservation Biology*, *12*, 399–407.

Fernández-Llamazares, Á., López-Baucells, A., Velazco, P. M., Gyawali, A., Rocha, R., Terraube, J., & Cabeza, M. (2021). The importance of Indigenous Territories for conserving bat diversity across the Amazon biome. *Perspectives in Ecology and Conservation*, *19*, 10–20.

Fisher-Phelps, M., Cao, G., Wilson, R. M., & Kingston, T. (2017). Protecting bias: Across time and ecology, open-source bat locality data are heavily biased by distance to protected area. *Ecological Informatics*, *40*, 22–34.

Frick, W. F., Kingston, T., & Flanders, J. (2020). A review of the major threats and challenges to global bat conservation. *Annals of the New York Academy of Sciences*, *1469*, 5–25.

García, F. J., Ochoa-G, J., Poma-Urey, J. L., Miller, B. W., Falcão, F. C., & Del Valle Alvarez, M. R. (2024). Expanding the knowledge of the bat fauna of the Brazilian Caatinga: New geographical records of molossid bats (Chiroptera, Molossidae) for the Chapada Diamantina region, with taxonomic notes. *ZooKeys*, *1210*, 333–371.

Godet, L., & Devictor, V. (2018). What conservation does. *Trends in Ecology & Evolution*, *33*, 720–730.

Grunwald, A. L., Demos, T. C., Nguéagni, Y., Tchamba, M. N., Monadjem, A., Webala, P. W., Peterhans, J. C. K., Patterson, B. D., & Ruedas, L. A. (2023). A review of bats of the genus *Pseudoromicia* (Chiroptera: Vespertilionidae) with the description of a new species. *Systematics and Biodiversity*, *21*, Article 2156002.

Herkt, K. M. B., Barnikel, G., Skidmore, A. K., & Fahr, J. (2016). A high-resolution model of bat diversity and endemism for continental Africa. *Ecological Modelling*, *320*, 9–28.

Hijmans, R. J., Bivand, R., Dyba, K., Pebesma, E., & Sumner, M. D. (2024). Package terra. https://cran.r-project.org/package=terra

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, *25*, 1965–1978.

Hijmans, R. J., Phillips, S., Leathwick, J., & Elith, J. (2010). *dismo: Species distribution modeling*. https://CRAN.R-project.org/package=dismo

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T. M., Butchart, S. H. M., Carpenter, K. E., Chanson, J., Collen, B., Cox, N. A., Darwall, W. R. T., Dulvy, N. K., Harrison, L. R., Katariya, V., Pollock, C. M., Quader, S., Richman, N. I., Rodrigues, A. S. L., Tognelli, M. F., … Stuart, S. N. (2010). The impact of conservation on the status of the world's vertebrates. *Science*, *330*, 1503–1509.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). (2019). *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Zenodo. https://zenodo.org/doi/10.5281/zenodo.3831673

International Union for Conservation of Nature (IUCN). (2024). *The IUCN Red List of Threatened Species. Version 2024-1*. http://www.iucnredlist.org

Jantz, S. M., Barker, B., Brooks, T. M., Chini, L. P., Huang, Q., Moore, R. M., Noel, J., & Hurtt, G. C. (2015). Future habitat loss and extinctions driven by land-use change in biodiversity hotspots under four scenarios of climate-change mitigation. *Conservation Biology*, *29*, 1122–1131.

Jennings, M. D. (2000). Gap analysis: Concepts, methods, and recent results. *Landscape Ecology*, *15*, 5–20.

Jones, G., Jacobs, D., Kunz, T., Willig, M., & Racey, P. (2009). Carpe noctem: The importance of bats as bioindicators. *Endangered Species Research*, *8*, 93–115.

Kingston, T. (2016). Cute, creepy, or crispy—How values, attitudes, and norms shape human behavior toward bats. In C. C. Voigt & T. Kingston (Eds.), *Bats in the Anthropocene: Conservation of bats in a changing world* (pp. 571–595). Springer.

Kingston, T., Francis, C. M., Akbar, Z., & Kunz, T. H. (2003). Species richness in an insectivorous bat assemblage from Malaysia. *Journal of Tropical Ecology*, *19*, 67–79.

Kunz, T. H., Braun De Torrez, E., Bauer, D., Lobova, T., & Fleming, T. H. (2011). Ecosystem services provided by bats. *Annals of the New York Academy of Sciences*, *1223*, 1–38.

Laverty, T. M., & Berger, J. (2022). Indirect effects of African megaherbivore conservation on bat diversity in the world's oldest desert. *Conservation Biology*, *36*, Article e13780.

Liu, Z., He, C., & Wu, J. (2016). The relationship between habitat loss and fragmentation during urbanization: An empirical evaluation from 16 world cities. *PLoS ONE*, *11*, Article e0154613.

Mande, C., VanCakenberghe, V., Kirkpatrick, L., Laudisoit, A., DeBruyn, L., Gembu, G.-C., & Verheyen, E. (2023). Drivers affecting habitat use in Afrotropical hipposiderid and pteropodid bats. *Biotropica*, *55*, 920–932.

Masolele, R. N., Marcos, D., De Sy, V., Abu, I.-O., Verbesselt, J., Reiche, J., & Herold, M. (2024). Mapping the diversity of land uses following deforestation across Africa. *Scientific Reports*, *14*, Article 1681.

McCleery, R., Monadjem, A., Baiser, B., Fletcher, R., Vickers, K., & Kruger, L. (2018). Animal diversity declines with broad-scale homogenization of canopy cover in African savannas. *Biological Conservation*, *226*, 54–62.

Meijaard, E., Sheil, D., Nasi, R., Augeri, D., Rosenbaum, B., Iskandar, D., Setyawati, T., Lammertink, A., Rachmatika, I., Wong, A., Soehartono, T., Stanley, S., & O'Brien, T. (2005). *Life after logging: Reconciling wildlife conservation and production forestry in Indonesian Borneo*. https://www.cifor-icraf.org/knowledge/publication/1663/

Meyer, C. F. J., Aguiar, L. M. S., Aguirre, L. F., Baumgarten, J., Clarke, F. M., Cosson, J.-F., Villegas, S. E., Fahr, J., Faria, D., Furey, N., Henry, M., Hodgkison, R., Jenkins, R. K. B., Jung, K. G., Kingston, T., Kunz, T. H., Cristina Macswiney Gonzalez, M., Moya, I., Patterson, B. D., … Kalko, E. K. V. (2011). Accounting for detectability improves estimates of species richness in tropical bat surveys: Species detectability in tropical bat surveys. *Journal of Applied Ecology*, *48*, 777–787.

Meyer, C. F. J., Struebig, M. J., & Willig, M. R. (2016). Responses of tropical bats to habitat fragmentation, logging, and deforestation. In C. C. Voigt & T. Kingston (Eds.), *Bats in the Anthropocene: Conservation of bats in a changing world* (pp. 63–104). Springer.

Mickleburgh, S., Waylen, K., & Racey, P. (2009). Bats as bushmeat: A global review. *Oryx*, *43*, 217–234.

Mildenstein, T., Tanshi, I., & Racey, P. A. (2016). Exploitation of bats for bushmeat and medicine. In C. C. Voigt & T. Kingston (Eds.), *Bats in the Anthropocene: Conservation of bats in a changing world* (pp. 325–375). Springer.

Monadjem, A., Demos, T. C., Dalton, D. L., Webala, P. W., Musila, S., Kerbis Peterhans, J. C., & Patterson, B. D. (2021). A revision of pipistrelle-like bats (Mammalia: Chiroptera: Vespertilionidae) in East Africa with the description of new genera and species. *Zoological Journal of the Linnean Society*, *191*, 1114–1146.

Monadjem, A., Farooq, H., & Kane, A. (2024). Elevation filters bat, rodent and shrew communities differently by morphological traits. *Diversity and Distributions*, *30*, Article e13801.

Monadjem, A., Guyton, J., Naskrecki, P., Richards, L. R., Kropff, A. S., & Dalton, D. L. (2020). Cryptic diversity in the genus *Miniopterus* with the description of a new species from Southern Africa. *Acta Chiropterologica*, *22*, 1–19.

Monadjem, A., Montauban, C., Webala, P. W., Laverty, T. M., Bakwo-Fils, E. M., Torrent, L., Tanshi, I., Kane, A., Rutrough, A. L., Waldien, D. L., & Taylor, P. J. (2024). African bat database: Curated data of occurrences, distributions and conservation metrics for sub-Saharan bats. *Scientific Data*, *11*, Article 1309.

Monadjem, A., Shapiro, J. T., Richards, L. R., Karabulut, H., Crawley, W., Nielsen, I. B., Hansen, A., Bohmann, K., & Mourier, T. (2019). Systematics of West African *Miniopterus* with the description of a new species. *Acta Chiropterologica*, *21*, 237–256.

Monadjem, A., Taylor, P. J., Cotterill, F. P. D., & Schoeman, M. C. (2020). *Bats of southern and central Africa: A biogeographic and taxonomic synthesis* (2nd ed.). Wits University Press.

Monadjem, A., & Unwin, M. (2023). *African ark: Mammals, landscape and the ecology of a continent*. NYU Press.

Oliveira, U., Soares-Filho, B. S., Paglia, A. P., Brescovit, A. D., De Carvalho, C. J. B., Silva, D. P., Rezende, D. T., Leite, F. S. F., Batista, J. A. N., Barbosa, J. P. P. P., Stehmann, J. R., Ascher, J. S., De Vasconcelos, M. F., De Marco, P., Löwenberg-Neto, P., Ferro, V. G., & Santos, A. J. (2017). Biodiversity conservation gaps in the Brazilian protected areas. *Scientific Reports*, *7*, Article 9141.

Paradis, E., & Schliep, K. (2019). ape 5.0: An environment for modern phylogenetics and evolutionary analyses in R. *Bioinformatics*, *35*, 526–528.

Parker, D. M., & Bernard, R. T. F. (2023). Bat functional diversity along the Chobe River Floodplain, Botswana. *African Journal of Wildlife Research*, *53*, 45–55.

Patterson, B. D., Demos, T. C., Torrent, L., Grunwald, A. L., Montauban, C., Kerbis Peterhans, J. C., Mcdonough, M. M., Dick, C. W., Bartonjo, M., Schoeman, M. C., Ruedas, L. A., & Juste, J. (2024). Systematics of the *Rhinolophus landeri* complex, with evidence for 3 additional Afrotropical bat species. *Journal of Mammalogy*, *106*, 187–201.

Pereira, H. M., Martins, I. S., Rosa, I. M. D., Kim, H., Leadley, P., Popp, A., Van Vuuren, D. P., Hurtt, G., Quoss, L., Arneth, A., Baisero, D., Bakkenes, M., Chaplin-Kramer, R., Chini, L., Di Marco, M., Ferrier, S., Fujimori, S., Guerra, C. A., Harfoot, M., … Alkemade, R. (2024). Global trends and scenarios for terrestrial biodiversity and ecosystem services from 1900 to 2050. *Science*, *384*, 458–465.

Pessoa Da Silva, F., & De Marco Júnior, P. (2023). The role of protected areas in safeguarding bat diversity in Brazil. *Biodiversity and Conservation*, *32*, 2909–2924.

R Core Team. (2022). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Rautenbach, I. L. (1982). *Mammals of the Transvaal* (PhD dissertation). University of Natal.

Razgour, O., Rebelo, H., Di Febbraro, M., & Russo, D. (2016). Painting maps with bats: Species distribution modelling in bat research and conservation. *Hystrix, the Italian Journal of Mammalogy*, *27*, Article 11753. https://doi.org/10.4404/hystrix-27.1-11753

Revell, L. J. (2024). phytools 2.0: An updated R ecosystem for phylogenetic comparative methods (and other things). *PeerJ*, *12*, Article e16505.

Rocha, R., Aziz, S. A., Brook, C. E., Carvalho, W. D., Cooper-Bohannon, R., Frick, W. F., Huang, J. C.-C., Kingston, T., López-Baucells, A., Maas, B., Mathews, F., Medellin, R. A., Olival, K. J., Peel, A. J., Plowright, R. K., Razgour, O., Rebelo, H., Rodrigues, L., Rossiter, S. J., … Webala, P. W. (2021). Bat conservation and zoonotic disease risk: A research agenda to prevent misguided persecution in the aftermath of COVID-19. *Animal Conservation*, *24*, 303–307.

Rodrigues, A. S. L., Andelman, S. J., Bakarr, M. I., Boitani, L., Brooks, T. M., Cowling, R. M., Fishpool, L. D. C., Da Fonseca, G. A. B., Gaston, K. J., Hoffmann, M., Long, J. S., Marquet, P. A., Pilgrim, J. D., Pressey, R. L., Schipper, J., Sechrest, W., Stuart, S. N., Underhill, L. G., Waller, R. W., … Yan, X. (2004). Effectiveness of the global protected area network in representing species diversity. *Nature*, *428*, 640–643.

Russo, D., & Ancillotto, L. (2015). Sensitivity of bats to urbanization: A review. *Mammalian Biology*, *80*, 205–212.

Sanders, E., Wassens, S., Michael, D. R., Nimmo, D. G., & Turner, J. M. (2024). Extinction risk of the world's freshwater mammals. *Conservation Biology*, *38*, Article e14168.

Schipper, J., Chanson, J. S., Chiozza, F., Cox, N. A., Hoffmann, M., Katariya, V., Lamoreux, J., Rodrigues, A. S. L., Stuart, S. N., Temple, H. J., Baillie, J., Boitani, L., Lacher, T. E., Mittermeier, R. A., Smith, A. T., Absolon, D., Aguiar, J. M., Amori, G., Bakkour, N., … Young, B. E. (2008). The status of the world's land and marine mammals: Diversity, threat, and knowledge. *Science*, *322*, 225–230.

Sherman, A., Geiselman, C., Poelen, J., Simmons, N., Reeder, D., Upham, N., Phelps, K., & Agosti, D. (2023). *A standardized review of bat names across multiple taxonomic authorities*. Zenodo. https://zenodo.org/records/7915722

Simmons, N. B., & Cirranello, A. L. (2025). *Bat Species of the World: A taxonomic and geographic database. Version 1.7*. https://batnames.org/home.html

Simmons, N. B., Flanders, J., Bakwo, E. M. F., Parker, G., Suter, J. D., Bamba, S., Douno, M., Keita, M. K., Morales, A. A., & Frick, W. F. (2021). A new dichromatic species of *Myotis* (Chiroptera: Vespertilionidae) from the Nimba Mountains, Guinea. *American Museum Novitates*, *2020*(3963), 1–40.

Storch, D., Šímová, I., Smyčka, J., Bohdalková, E., Toszogyova, A., & Okie, J. G. (2022). Biodiversity dynamics in the Anthropocene: How human activities change equilibria of species richness. *Ecography*, *2022*, Article ecog.05778.

Struebig, M. J., Christy, L., Pio, D., & Meijaard, E. (2010). Bats of Borneo: Diversity, distributions and representation in protected areas. *Biodiversity and Conservation*, *19*, 449–469.

Sutherland, W. J., Taylor, N. G., MacFarlane, D., Amano, T., Christie, A. P., Dicks, L. V., Lemasson, A. J., Littlewood, N. A., Martin, P. A., Ockendon, N., Petrovan, S. O., Robertson, R. J., Rocha, R., Shackelford, G. E., Smith, R. K., Tyler, E. H. M., & Wordley, C. F. R. (2019). Building a tool to overcome barriers in research-implementation spaces: The Conservation Evidence database. *Biological Conservation*, *238*, Article 108199.

Symes, W. S., Rao, M., Mascia, M. B., & Carrasco, L. R. (2016). Why do we lose protected areas? Factors influencing protected area downgrading, downsiz-

ing and degazettement in the tropics and subtropics. *Global Change Biology*, *22*, 656–665.

Synes, N. W., & Osborne, P. E. (2011). Choice of predictor variables as a source of uncertainty in continental-scale species distribution modelling under climate change: Predictor uncertainty in species distribution models. *Global Ecology and Biogeography*, *20*, 904–914.

Tackett, E. S., Kingston, T., Sadeghmoghaddam, N., & Rutrough, A. L. (2022). Global medicinal use of bats: A systematic literature and social media review. *Diversity*, *14*, Article 179.

Tanalgo, K. C., & Hughes, A. C. (2025). Bat Cave Vulnerability Index 3.0 (BCVI-S): An integrative and scalable tool to prioritise bat caves for conservation. *Global Ecology and Conservation*, *57*, Article e03396.

Tanalgo, K. C., Oliveira, H. F. M., & Hughes, A. C. (2022). Mapping global conservation priorities and habitat vulnerabilities for cave-dwelling bats in a changing world. *Science of the Total Environment*, *843*, Article 156909.

Tanalgo, K. C., Sritongchuay, T., Agduma, A. R., Dela Cruz, K. C., & Hughes, A. C. (2023). Are we hunting bats to extinction? Worldwide patterns of hunting risk in bats are driven by species ecology and regional economics. *Biological Conservation*, *279*, Article 109944.

Tanshi, I., & Kingston, T. (2021). Introduction and implementation of harp traps signal a new era in bat research. In B. K. Lim, M. B. Fenton, R. M. Brigham, S. Mistry, A. Kurta, E. H. Gillam, A. Russell, & J. Ortega (Eds.), *50 years of bat research* (pp. 255–270). Springer.

Tanshi, I., Obitte, B. C., Monadjem, A., & Kingston, T. (2021). Hidden Afrotropical bat diversity in Nigeria: Ten new country records from a biodiversity hotspot. *Acta Chiropterologica*, *23*, 313–343.

Tittensor, D. P., Walpole, M., Hill, S. L. L., Boyce, D. G., Britten, G. L., Burgess, N. D., Butchart, S. H. M., Leadley, P. W., Regan, E. C., Alkemade, R., Baumung, R., Bellard, C., Bouwman, L., Bowles-Newark, N. J., Chenery, A. M., Cheung, W. W. L., Christensen, V., Cooper, H. D., Crowther, A. R., … Ye, Y. (2014). A mid-term analysis of progress toward international biodiversity targets. *Science*, *346*, 241–244.

Tuneu-Corral, C., Andrianalijaona, C., Benirina, F. D., Goodman, S. M., Mata, V. A., Tantely, M. L., Cabeza, M., Montauban, C., López-Bosch, D., & Lopez-Baucells, A. (2025). Beyond borders: The role of protected areas in promoting bat-mediated pest suppression in rural areas of Madagascar. *Agriculture, Ecosystems & Environment*, *387*, Article 109590.

Tuneu-Corral, C., Puig-Montserrat, X., Riba-Bertolín, D., Russo, D., Rebelo, H., Cabeza, M., & López-Baucells, A. (2023). Pest suppression by bats and management strategies to favour it: A global review. *Biological Reviews*, *98*, 1564–1582.

Turpie, J. K., & Crowe, T. M. (1994). Patterns of distribution, diversity and endemism of larger African Mammals. *South African Journal of Zoology*, *29*, 19–32.

Tyukavina, A., Hansen, M. C., Potapov, P., Parker, D., Okpa, C., Stehman, S. V., Kommareddy, I., & Turubanova, S. (2018). Congo Basin forest loss dominated by increasing smallholder clearing. *Science Advances*, *4*, Article eaat2993.

UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), & International Union for Conservation of Nature (IUCN). (2024). *The World Database on Protected Areas*. UNEP-WCMC. http://wcmc.io/PP_WDPA

Upham, N. S., Esselstyn, J. A., & Jetz, W. (2019). Inferring the mammal tree: Species-level sets of phylogenies for questions in ecology, evolution, and conservation. *PLoS Biology*, *17*, Article e3000494.

Van Breugel, P., Kindt, R., Lillesø, J.-P. B., & Van Breugel, M. (2015). Environmental gap analysis to prioritize conservation efforts in Eastern Africa. *PLoS ONE*, *10*, Article e0121444.

Van Cakenberghe, V., & Seamark, E. C. J. (2023). *Africa Chiroptera Report 2023*. AfricanBats NPC.

Van Proosdij, A. S. J., Sosef, M. S. M., Wieringa, J. J., & Raes, N. (2016). Minimum required number of specimen records to develop accurate species distribution models. *Ecography*, *39*, 542–552.

Venter, O., Fuller, R. A., Segan, D. B., Carwardine, J., Brooks, T., Butchart, S. H. M., Di Marco, M., Iwamura, T., Joseph, L., O'Grady, D., Possingham, H. P., Rondinini, C., Smith, R. J., Venter, M., & Watson, J. E. M. (2014). Targeting global protected area expansion for imperiled biodiversity. *PLoS Biology*, *12*, Article e1001891.

Visconti, P., Pressey, R. L., Giorgini, D., Maiorano, L., Bakkenes, M., Boitani, L., Alkemade, R., Falcucci, A., Chiozza, F., & Rondinini, C. (2011). Future hotspots of terrestrial mammal loss. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*, 2693–2702.

Watson, J. E. M., Dudley, N., Segan, D. B., & Hockings, M. (2014). The performance and potential of protected areas. *Nature*, *515*, 67–73.

Western, D., Russell, S., & Cuthill, I. (2009). The status of wildlife in protected areas compared to non-protected areas of Kenya. *PLoS ONE*, *4*, Article e6140.

Wisz, M. S., Hijmans, R. J., Li, J., Peterson, A. T., Graham, C. H., Guisan, A., & NCEAS Predicting Species Distributions Working Group. (2008). Effects of sample size on the performance of species distribution models. *Diversity and Distributions*, *14*, 763–773.

Wolkovich, E. M., Cook, B. I., McLauchlan, K. K., & Davies, T. J. (2014). Temporal ecology in the Anthropocene. *Ecology Letters*, *17*, 1365–1379.

Wood, M. R., De Vries, J. L., Monadjem, A., & Markotter, W. (2024). Review and meta-analysis of correlates of home range size in bats. *Journal of Mammalogy*, *105*, 1044–1056.

Yu, G., Smith, D. K., Zhu, H., Guan, Y., & Lam, T. T. (2017). GGTREE: An R package for visualization and annotation of phylogenetic trees with their covariates and other associated data. *Methods in Ecology and Evolution*, *8*, 28–36.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Montauban, C., Budinski, I., Webala, P. W., Laverty, T. M., Tanshi, I., Torrent, L., Bakwo-Fils, E., Taylor, P. J., Kane, A., & Monadjem, A. (2025). Underrepresentation of bats in Africa's protected areas. *Conservation Biology*, e70108. https://doi.org/10.1111/cobi.70108