Anthropogenic structures promote frequent and intense contact between humans and bats in rural Kenya

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ABSTRACT

1. Simultaneous use of domestic spaces by humans and wildlife is little understood, despite global ubiquity, and can create an interface for human exposure to wildlife pathogens. Bats are associated with several pathogens that can spillover and cause disease in humans and, due to loss of natural habitat and urbanization, are increasingly using anthropogenic structures for roosting. The purpose of this study was to characterize human interactions with bats in shared buildings to assess potential for exposure risk to bat pathogens.
2. We surveyed 102 people living and working in buildings used as bat roots in rural Kenya between 2021 and 2023. Based on responses, we characterized and quantified the timing, intensity, and frequency of human-bat interactions occurring in this common domestic setting.
3. Survey respondents reported living with bats in buildings year-round, with cohabitation occurring for at least 10 years in 38% of cases. Human contact with bats occurred through direct and indirect routes, including exposure to excrement (90% of respondents), and direct touching of bats (39% of respondents). Indirect contacts most often occurred daily and direct contacts most often occurred yearly. Domestic animal consumption of bats was also reported (16% respondents).
4. *Synthesis and applications* : We demonstrate that shared building use by bats and humans in rural Kenya leads to prolonged, frequent, and sometimes intense interactions between bats and humans, consistent with exposure interfaces that can facilitate pathogen spillover. Identifying and understanding the settings and practices that may lead to zoonotic pathogen spillover is of great global importance for developing countermeasures, and this study establishes bat roosts in anthropogenic structures as such a setting.

KEYWORDS

Africa, Chiroptera, emerging infectious disease, human-wildlife interaction, spillover, wildlife conflict, zoonosis

INTRODUCTION

Emerging infectious diseases (EIDs) are a significant threat to global health and security, as demonstrated by the recent COVID-19 pandemic and Mpox disease outbreak (Morens and Fauci 2013, Wang et al. 2022, Zumla et al. 2022). Most EIDs have zoonotic origins and emerge in humans via spillover of pathogens from animals, often wildlife (Jones et al. 2008). These risks are exacerbated by growing human populations and conversion of natural lands to anthropogenic regions, which increase human contacts with wildlife and exposure to their pathogens (Woolhouse and Gowtage-Sequeria 2005, Jones et al. 2008, Gottdenker et al. 2014).

Settings and practices that lead to pathogen spillover are little understood but of great importance for informing outbreak mitigation strategies. In lieu of direct knowledge on pathogen exposure, which is extremely difficult to identify from wild animals, characterization of human-wildlife contact can be used to infer exposure risk. Identifying exposure settings has primarily focused on direct contact between humans and wildlife, largely in the form of wildlife hunting and markets for the sale of live animals (Karesh et al. 2005, Mossoun et al. 2015, Keatts et al. 2021, Nawtaisong et al. 2022). For example, wildlife consumption and associated handling and butchering creates human contact with wildlife viscera and bodily fluids, which can facilitate spillover of their pathogens (Wolfe et al. 2005). However, contacts between humans and wildlife occur across numerous settings outside of wildlife trade and consumption and can result in human exposure to wildlife pathogens (Plowright et al. 2017). Other settings and practices that promote contact between wildlife and humans have received far less focus despite the importance of their characterization to mitigating zoonotic pathogen spillover.

Wildlife often share spaces with humans and domestic animals, especially in the Global South, where humans and wildlife coexist closely in developing landscapes and EID risk is high (Seoraj-Pillai and Pillai 2016, Allen et al. 2017). Studies have reported many communities struggling to manage small mammal incursion into buildings (Salmon-Mulanovich et al. 2016, Doty et al. 2017, Balčiauskas and Balčiauskiene 2020). The presence of mammals in these spaces can create opportunities for human and domestic animal contact with wildlife and their excreta, potentially exposing them to wildlife-borne pathogens (Ogola et al. 2021). Despite the risk, characterization and quantification of contacts within buildings, where people may spend significant portions of their lives, is lacking.

Bats can harbor zoonotic pathogens that may be shed in excreta and bodily fluids (eg., feces, urine, saliva, blood, etc.; Mildenstein et al. 2016, Waruhiu et al. 2017). Several bat-borne viruses have emerged in humans after transmission from bats via indirect contact with bat excreta or direct contact with bat bodily fluids (Belotto et al. 2005, Epstein et al. 2006, Towner et al. 2009, Eby et al. 2023). Domestic animals can also be exposed to these pathogens after contact with bats excreta and fluids (Marsh and Wang 2004). In developing settings, anthropogenic structures, like family homes, places of worship, and schools, can be highly permeable to bats, and with ongoing habitat loss bats are increasingly using these buildings as roosts (Russo and Ancillotto 2015, Voigt et al. 2016). Few options exist for people to safely manage bat use of their buildings, and this provides numerous opportunities for human-bat contact and conflict. However, detailed characterization of how humans contact bats and their excreta in relation to pathogen exposure risk in shared spaces is lacking and requires attention.

We investigated human-bat interactions in anthropogenic structures in rural south-eastern Kenya to characterize and quantify forms of contact that could lead to human exposure to bat pathogens. Bats are known to roost frequently in buildings simultaneously used by humans in this region (Musila et al. 2018, Jackson et al. 2023, Lunn et al. 2023) and this area has been forecasted as a hotspot for zoonotic pathogen emergence where surveillance and mitigation efforts are needed (Allen et al. 2017). By understanding these contacts and their potential to facilitate pathogen exposure, we can better identify human health risks in this interface and provide data necessary to mitigate risks.

METHODS

This study was conducted in Taita-Taveta County, Kenya. The most recent 2019 population estimate of Taita-Taveta County was 340,671 people in 2019 (Kenya National Bureau of Statistics), with a 1.8%

annual increase in population over the preceding 10 years. Almost three-quarters of the population is considered rural, although urbanization and deforestation are increasing substantially in the region (Platts et al. 2011, Nyongesa et al. 2022). This area is characterized by remnant patches of high-elevation cloud forest surrounded by low-elevation grasslands, woodlands, and agriculture (Abera et al. 2022).

We surveyed people in Taita-Taveta County during 2021 (August – October), 2022 (January – April), and 2023 (May – June) to understand and characterize human and domestic animal interactions with bats living in buildings. Participants were identified via word-of-mouth conversations with community members throughout the study area. We sought out adults who had bats in their homes (permanent and rental properties) or workplaces at the time of the survey, or who had evidence of recent sustained bat use (i.e., urine staining, fecal deposits, dead bats, etc.). Surveys were directed to one individual per property, however additional family members were sometimes present during questioning. Participants were informed about the study and verbal consent was obtained prior to conducting surveys. This research was approved by the National Commission for Science, Technology and Innovation (#NACOSTI/P/21/9267) and University of Arkansas Institutional Review Board (Protocol #2103320918).

Surveys were conducted in the local Taita language, Swahili, or English by local Taita assistants and at least one of the authors. Questions were read to respondents by the research team and answers were transcribed by the team. Our survey consisted of short-answer, dichotomous, and categorical questions to characterize resident human and domestic animal demographics of the property, the duration of bat use of the property and its buildings, and human and domestic animal interactions with bats and their excreta (see Supplementary Materials for detailed information on survey questions). Surveys from 2021 (n = 23) included 23 multi-part questions. After this initial data collection, we added one additional question to characterize human and domestic animal contact with dead bats on the property. Therefore, surveys conducted in 2022 and 2023 (n = 79) included 24 multi-part questions.

To explore the effect of the number of residents on the property, length of bat building use, and respondent demographics (gender, education, and age) on direct (e.g., touching, scratches, bites, etc.) and indirect (e.g., contact with bat excrement) interactions with bats, we used univariate generalized linear models with a binomial error distribution and logit link function. We used chi-square tests to compare the frequencies of bat interactions, length of time of bat occupation of buildings, exclusion methods, and reasons for exclusion. All analyses were conducted in R (Version 2023.06.2+561) using the stats package (v4.1.3).

RESULTS

We surveyed 102 people who lived or worked in buildings used by bats (Table S1). Over 70% of people reported bat use of their buildings for >5 years (n = 72), with bat presence for 5-10 years most commonly reported (χ^2 = 36.52, P< 0.01, Fig. 1). Most properties (88%) had bat presence year-round (n = 90). Survey participants described frequent exposure to bats that would support pathogen transmission through two main routes: direct and indirect (fecal/oral) contact, with indirect contact between bats and people reported more frequently than direct contacts (χ^2 = 24.77, P < 0.01, Fig. 2A).

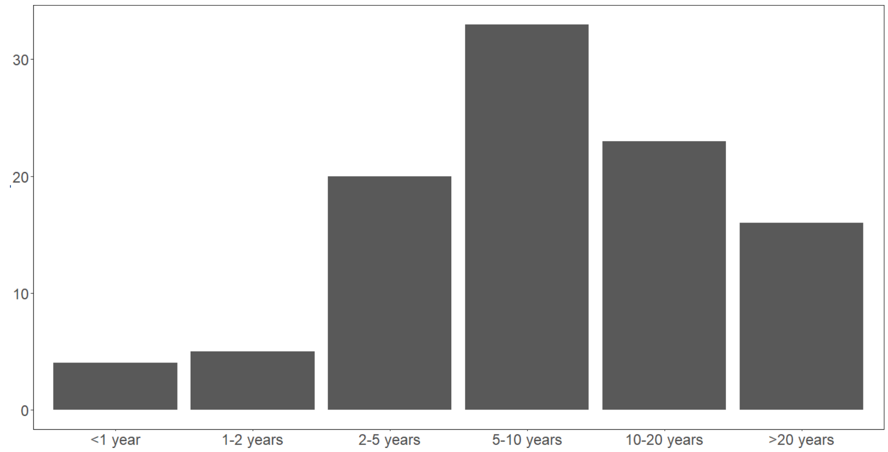

Figure 1. The number of respondents reporting the length of time bats had been present in their buildings. All but one participant answered this question.

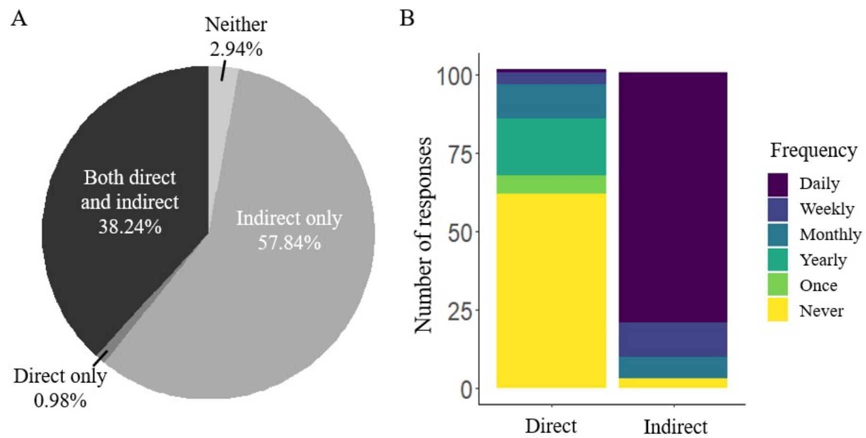

Figure 2. People surveyed about human-bat interactions in their buildings reported both direct (e.g., touching, scratches, bites, etc.) and indirect (e.g., contact with bat excrement) contacts between humans and bats. (A) Indirect interactions were the most reported of the two interaction types; (B) Frequency of these contacts varied from daily interactions to never having these interactions.

Close to half of participants (39%) reported direct contact with bats, including people touching bats (n = 40) and one report of being bitten. People on the property (children, spouses, custodians) other than the respondent engaged in these interactions as well. Direct interactions occurred with varying frequencies over time according to respondents (Fig. 2B). Reports of direct contact did not differ significantly based on the number of residents on the property, length of time of bat use, or respondent demographics (gender, education, and age; $P > 0.06$).

Over 90% of respondents reported indirect contact with bats, mostly through interactions with their feces and urine ($n = 98$). Daily occurrences of indirect contact were reported by most participants (78%, $\chi^2 = 285.06$, $P < 0.01$, Fig. 2B) and children, spouses, house guests, and custodians were also involved in these interactions. Reports of indirect contact did not differ significantly among the number of residents on the property, length of time of bat use, or respondent demographics (gender, education, and age; $P > 0.13$).

Attempts to remove bats from buildings create opportunities for direct human-bat contact and were reported by almost 80% of participants (n = 81). Of those reporting removal efforts, almost half reported direct contact with bats (n = 34). Numerous removal methods were reported, with fumigation via pesticide, blocking access to building entry points, and scaring bats from buildings reported more than other methods ($\chi^2 = 107.37$, $P < 0.01$; Table 1). Bats returned to the property after removals in over 90% of cases (n = 76). Bad smells (n = 39), noise (n = 39), dirt from feces and urine (n = 36), and damage to property (n = 21) were the most common reasons reported for removing bats. Significantly fewer respondents mentioned worries about witchcraft (n = 15), that bats were a general nuisance (n=12) or posed health risks to people (n = 8) compared to more common removal reasons ($\chi^2 = 123.47$, $P < 0.01$).

Table 1. Methods used by people to remove bats from buildings. Attempts to remove bats were common and frequently led to direct contact with bats that could facilitate pathogen exposure.

Type of removal effort	Number of responses (%)
Fumigation via pesticide	36 (44.44)
Blocking access to buildings	25 (30.86)
Scaring bats	22 (27.16)
Killing individual bats	19 (23.46)
Smoking bats out	5 (6.17)
Application of holy water	2 (2.47)
Removal of ceiling	2 (2.47)
Application of salt	2 (2.47)
Killing via domestic animal	1 (1.23)

We asked a subset of participants about the presence of dead bats on their properties (n = 79). Nearly 65% reported dead bats on properties (n = 51). Most removed dead bats, usually by throwing them over property lines (n = 30) or swept them outside (n= 7). Some also reported burning (n = 6), feeding to domestic cats (n = 2), and burying of carcasses (n = 1). Interestingly, 13 respondents reported seeing domestic animals (dogs, cats, and chickens) consume dead bats on their property, most often their own animals.

DISCUSSION

We establish that buildings are a common interface for human-bat contact in rural Africa and that these interactions can be intense, frequent, and occur consistently over long periods of time. Our survey respondents had exposure to bats in ways that can promote pathogen transmission through direct or indirect pathways, as well as via domestic animals. Much attention has focused on bushmeat hunting and wet markets as high-risk practices and settings for wildlife pathogen exposure risk. Given the increasing rate of urbanization and subsequent habitat loss bats are experiencing, anthropogenic structure sharing by humans and bats is likely to become more common across the globe and a greater risk setting for zoonotic spillover.

Our results show that bats and humans contacted each other directly (e.g., touching, scratches, bites, etc.) and indirectly (e.g., contact with bat excrement). Direct contacts can expose humans to lethal viruses hosted by bats, with various lyssaviruses (including rabies virus) being the most well-known bat-borne pathogens transmitted in this manner (Warrell and Warrell 2004). Indirect contacts were frequently reported in our study and are also common pathways for zoonotic pathogen transmission (Loh et al. 2015). Bat excreta reported in these indirect interactions, mostly feces, can contain pathogens shed by bats in this region, including coronaviruses, rotaviruses, and paramyxoviruses that are viral families of concern (Waruhiu et al. 2017). Fungal pathogens, like *Histoplasma capsulatum* , the causative agent of histoplasmosis, may also be inhaled from bat fecal dust and have infected people living in buildings with bat roosts in Africa (Ocansey et al. 2022).

Multiple respondents reported observing domestic animals – mainly cats, dogs, and chickens – consuming bats. Predation and consumption of bats can facilitate transmission of zoonotic parasites into consumers, including domestic animals (Karesh and Noble 2009), which can also serve as bridge hosts for onward transmission to humans (Salinas-Ramos et al. 2021). Furthermore, bats will roost in livestock enclosures in this region and may deposit feces or bodily fluids in spaces frequently used by domestic animals (Jackson et al. 2023). Many frugivorous bat species may chew and eject saliva-covered fruit pulp below their roosts, which domestic animals may also then consume and become exposed to shed pathogens (Openshaw et al. 2016). Indeed, it has been proposed that Nipah and Hendra virus, both paramyxoviruses, emerged in pigs and horses in this fashion, respectively (Marsh and Wang 2012).

Our results show that community members attempted to remove bats from their buildings, mostly via fumigation with pesticides, blocking off bat entrance points, and direct killing of bats. These activities often led to direct human contact with bats, creating additional opportunities for pathogen exposure. Stress to bats caused by removal attempts can also increase pathogen transmission risk by altering bat behavior and immune function, which collectively drive contact rates and viral susceptibility and shedding (Streicker et al. 2013, Amman et al. 2014, Torquetti et al. 2021). Furthermore, high bat mortality rates can also negatively impact the critical ecosystem services that bats provide by reducing their ability to consume insect pests, pollinate fruit trees, and disperse seeds (Kunz et al. 2011).

The presence of bats in buildings is a common occurrence in developing settings, and our findings establish that there are frequent and prolonged interactions between humans and bats, consistent with interactions that can facilitate pathogen spillover. With a growing and urbanizing human population, as well as the destruction of natural roosting sites for bats, it is likely that cohabitation of bats and humans in anthropogenic structures will continue to increase globally (Russo and Ancillotto 2015, Voigt et al. 2016). While we establish the importance of this interface, further work is needed to identify the risks from co-habiting synanthropic wildlife in these domestic spaces, including zoonotic pathogen presence and potential for transmission.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to report.

AUTHOR CONTRIBUTIONS

Reilly T. Jackson, Joseph G. Ogola, Paul W. Webala, and Kristian M. Forbes conceived the ideas and designed methodology. Reilly T. Jackson, Tamika. J. Lunn, Isabella K. DeAnglis, Joseph G. Ogola, and Paul W. Webala collected the data; Reilly T. Jackson analyzed the data; Reilly T. Jackson led the writing of the manuscript. All authors contributed to edits and approval the final manuscript.

STATEMENT ON INCLUSION

This study brings together authors from the United States and Kenya, where the study was conducted. Authors from both countries worked together from this project's inception to develop the methodology and survey used in this study. When possible, literature written by authors from this region was cited in the manuscript. Findings from this study will be disseminated to communities participating in this research in their local language.

DATA ACCESSIBILITY

Declassified data from this study will be published on Figshare pending acceptance.

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