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Short Communication

Active predation by brown rats (*Rattus norvegicus*) on bats at urban mass hibernacula in Northern Germany: Conservation and one health implications

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ABSTRACT

This study is the first to document systematic predation by *Rattus norvegicus* on bats at urban hibernacula hosting several thousand individuals in Europe. Using infrared video surveillance and thermal imaging at two major sites in Northern Germany (Segeberg and Lüneburg Kalkberg) used predominantly by *Myotis* species, we observed aerial interception and ground-based hunting strategies targeting swarming bats. The predation behavior highlights the remarkable manipulative abilities and behavioral plasticity of brown rats in urban ecosystems. Our findings suggest significant additional mortality risks for bat populations at mass hibernacula and raise concerns about potential pathogen exchange between two major wildlife reservoirs. We recommend targeted rodent management strategies to mitigate conservation and public health risks in line with One Health approaches.

1. Introduction

The global biodiversity crisis, widely recognized as defaunation, poses significant threats to ecosystem stability, wildlife populations, and human well-being (Finn et al., 2023). Recent global analyses indicate approximately 56 % of assessed mammalian species have decreasing population trends (Finn et al., 2023). Among those few successful species, invasive rodents - particularly members of the family *Muridae* - represent a significant ecological and economic threat worldwide (Diagne et al., 2023, Puckett et al., 2016, Puckett and Munshi-South, 2019). Invasive rodents have historically been responsible for severe biodiversity loss on islands, causing declines or even extinctions of endemic species (Towns et al., 2006; Nance et al., 2023). While the black rat (*Rattus rattus*) is the most widespread invasive rat species in the tropics (Shiels et al., 2014), recent observations show that urban environments in Central Europe are also susceptible to invasive rodent species such as the brown rat (*Rattus norvegicus*).This is one of the most pervasive invasive mammals, globally distributed and known to negatively impact native wildlife through competition, habitat alteration, and direct predation (Harper and Bunbury, 2015). Urbanization facilitates the proliferation of *R. norvegicus* by providing abundant food sources and shelter, leading to unprecedentedly high rodent densities in urban green spaces (Cock et al., 2024). High densities of invasive

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rodents in urban environments potentially increase the predation pressure on native wildlife species, which already face stressors from habitat fragmentation and environmental changes (Faeth et al., 2011). Brown rats are primarily known as predators of ground-nesting wildlife - they prey on eggs and nestlings of waterfowl and seabirds (Angelici et al., 2012; Harper and Bunbury, 2015; Bregnballe et al., 2022) - but their interactions with airborne prey such as bats are still largely undocumented.

Bats play critical ecological roles and deliver substantial ecosystem services worldwide, including insect suppression, seed dispersal and pollination (Kunz et al., 2011; Russo et al., 2018, 2023; Ramírez-Fráncel et al., 2022). Urbanization affects bats in heterogeneous, often species-specific ways: some species avoid densely built or highly sealed habitats, whereas others exploit urban structures opportunistically (Coleman and Barclay, 2012; Jung and Threlfall, 2016; Moretto et al., 2023). Large inner-city mass-wintering sites of *Myotis spp.*, however, are particularly vulnerable. These hibernacula recruit bats from wide catchment areas that increasingly face urban stressors such as intense light and noise pollution (Stone et al., 2015; Korine et al., 2023) and heavy road traffic (Berthinussen and Altringham, 2012). Additional predation pressure from invasive rodents could further compound these population-level stresses, exacerbate declines, and compromise critical ecosystem services provided by bats (Browning et al., 2021).

In Northern Germany, mass hibernacula in urban settings harbor large aggregations of bats, predominantly *Myotis* species (Borkenhagen, 2011). These hibernacula are critical for bat conservation in temperate regions (Mitchell-Jones et al., 2007). To assess the scale and potential conservation implications of invasive rodent predation on bats at mass hibernacula in continental Europe, we investigated two major urban bat hibernation sites in Northern Germany, the Segeberger Kalkberg and Lüneburger Kalkberg. Specifically, we aimed to document the extent of predation events by *R. norvegicus* on swarming and hibernating bats using infrared and thermal imaging technology. By providing detailed observations of predation behaviors and estimating the potential impact on local bat populations, our study addresses a significant knowledge gap. The findings also highlight the need for targeted conservation measures and integrated One Health strategies to mitigate risks posed by invasive rodents in urban ecosystems.

2. Methods

The Segeberger Kalkberg cave (53°56'08.2"N, 10°18'57.5"E) and the Lüneburger Kalkberg (53°14'57.29"N, 10°23'48.52"E) are two important bat hibernacula in Northern Germany (Fig. 1). The Segeberger Kalkberg cave serves as a winter roost for over 30,000 bats, predominantly *Myotis daubentonii* and *Myotis nattereri*, and is situated adjacent to a heavily visited open-air theatre attracting over 400,000 visitors annually (MELUND, 2019). The Lüneburger Kalkberg is located in a city park and characterized by frost-free rock crevices, but a cave system is currently unknown. Nevertheless, the immense swarming activities in late summer and autumn period show that the Lüneburger Kalkberg also supports substantial aggregations of *Myotis* species (several thousand individuals; Gloza-Rausch, unpublished data). Mist netting during the 2022 and 2024 swarming season confirmed that the species composition at the Lüneburger Kalkberg closely mirrors that of the Segeberger Kalkberg, with *M. nattereri* and *M. daubentonii* clearly predominating; other species like *M. bechsteinii, M.dasycneme, M.myotis, M. brandtii* and *Plecotus auritus* were only occasionally captured (Gloza-Rausch et al., unpublished data).

Predation events at the Segeberger Kalkberg were captured using Geutebrück G-CamEBC-3310 cameras equipped with 1/1.7″ 8 MP CMOS sensors and varifocal 4–13 mm lenses, providing a horizontal field of view of approximately 80°–30° and recording 4 K UHD video in H.264 and MJPEG formats. Each camera was paired with a G-Lite IR940-C 'no-glow' infrared illuminator (940 nm), which is invisible to humans and lies beyond the visual sensitivity of *R. norvegicus*, yielding effective illumination up to ~25 m (Thiele Hauselectronic GmbH), complementing an existing automated light barrier system (ChiroTEC Verhaltenssensorik und Umweltgutachten) used to count bats and monitor their activity at the cave entrances. As part of the light barrier system, black fabric was initially attached to the walls of the entrance area to enhance video contrast, inadvertently providing rats with a climbing aid and thus facilitating



Fig. 1. Location of the two urban mass-hibernacula investigated in this study. Overview map of northern Germany (WGS 84 / EPSG 3857) indicating the Segeberger Kalkberg and the Lüneburger Kalkberg (red pentagons) in relation to the nearest major cities, Hamburg and Berlin. *Bottom left*: Detail of the Segeberger Kalkberg and surrounding urban neighborhoods of Bad Segeberg (OpenStreetMap © contributors 2024 / LDBL). *Bottom right*: Detail of the Lüneburger Kalkberg within the city of Lüneburg (OpenStreetMap © contributors 2024 / LDBL). All maps share the same projection (WGS 84 / Pseudo-Mercator) and include 500 m scale bars for the insets. Map design by S. Barckmann, June 2025.

predation.

The fabric was removed when it was recognized during fieldwork for another study from August to October 2020 (Bergmann et al., 2022) that predation was not a singular event, but that observations of rat preying on bats occurred regularly. Whenever possible, we determined the bat species predated upon based on morphological characteristics. *Myotis daubentonii* was identified by its characteristic tail membrane shape and ear size. *Myotis nattereri* was distinguished by its longer ears and the presence of an S- shaped calcar, which gives the tail membrane a rounded appearance in flight, contrasting with the triangular shape seen in *M. daubentonii*.

At the Lüneburger Kalkberg, due to dense vegetation and complex terrain, we employed handheld thermal imaging devices (Pulsar Helion 2 XP50 Pro and Zeiss DTI 3/35) to document predation events. Observations were conducted annually between 2021 and 2024, covering at least four hours per night on multiple nights during periods of high bat activity in the peak swarming season (August–October), and at least three hours per night during the spring migration period (February–March). Thermal imaging allowed non-invasive documentation of bat and rodent behavior in complete darkness.

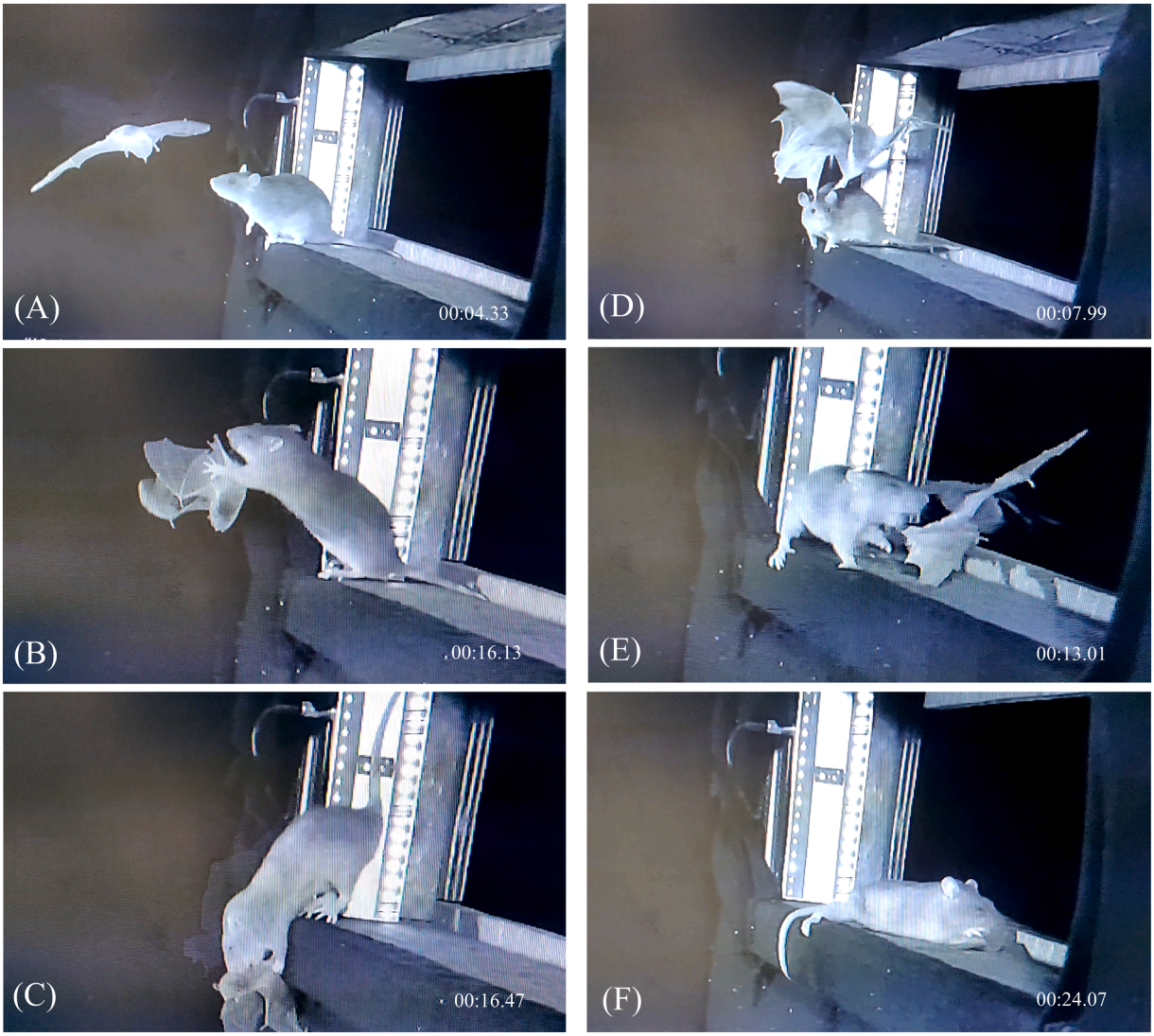

Fig. 2. Infrared video stills documenting predation behavior by brown rats (*Rattus norvegicus*) at the entrance to the Segeberg Kalkberg (Bad Segeberg, Germany). Aerial capture of a bat in flight. (A–C): The rat positions itself at the entrance (A), intercepts an approaching bat mid-air (B), and secures the prey with its forelimbs (C). Capture of a bat that landed on the platform near the light barrier system (D–F): The rat approaches the bat (D), jumps into the direction of the bat, uses its forelimbs to seize and immobilize the prey (E) and holds it firmly while preparing to transport it away (F). In all sequences, the rat skillfully uses its forelimbs to grasp, manipulate, and control the bat, while its tail provides balance and stability during the capture. These observations highlight the crucial role of forelimb coordination in both hunting strategies. The photographs show that brown rats, whose body mass is one to two orders of magnitude greater than that of Daubenton's or Natterer's bats, can readily overpower and carry these bats. Images were recorded in August and September 2020 during swarming activity.

3. Results

3.1. Predation behavior at Segeberger Kalkberg cave

Over a < 5-week period (late August – early October 2020), infrared video surveillance observed 30 predation attempts and 13 confirmed kills of *Myotis* bats by *R. norvegicus*. Rats of multiple sizes were seen, indicating that several individuals hunted in the vicinity of the light-barrier.

Two distinct hunting strategies were recorded (Supplementary Videos V1–4). 1) Aerial interception of bats during swarming (Fig. 2. A-C, Videos V1–2): Rats were frequently observed patrolling the landing platform at the cave entrance. They were standing upright on their hind legs, using their tails for balance and raising their forelegs to intercept flying bats. Individuals were documented capturing bats mid-air, killing them immediately with a bite and dragging them away. These behaviors were recorded under near-infrared illumination (940 nm) in complete darkness - a wavelength that is invisible to humans and falls beyond the primary visual sensitivity of *R. norvegicus* (Nader and Diamond, 2021). The rats most likely detected the bats via tactile cues from their vibrissae or by sensing the air currents generated by bat wingbeats (Fig. 3).

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2) Capture of resting or landed bats (Fig. 2. D-F, Videos V3–4): Rats also preyed on bats that landed on the platform, particularly *M. daubentonii*. Rats approached quickly, apparently detecting the bats with their vibrissae, lunged forward, and grasped them with their forelegs before delivering a fatal bite and carrying the prey away.

Moreover, an inspection of the light barrier system's entry boxes revealed a brown rat feeding site. In addition to rat droppings, the remains of at least 52 bats were found in a cache, clearly indicating regular feeding behavior and possibly food hoarding, as not all carcasses were fully consumed.

3.2. Predation behavior at Lüneburg Kalkberg

Evidence of rat predation on bats was also obtained at the Lüneburger Kalkberg. Between 2021 and 2024, nocturnal thermal-imaging surveys repeatedly detected *R. norvegicus* around crevices bats enter during the late-summer swarming season. Although no capture events were observed directly, a cache of bat carcasses was discovered deep in a rock fissure (Fig. 2). The spatial arrangement and condition of these remains closely resembled those documented at the Segeberger Kalkberg, indicating that brown rats likely prey on bats at the Lüneburger Kalkberg as well.

Brown rats live in resource-dependent social colonies; field and laboratory studies report group sizes from ≈ 15 to > 150



Fig. 3. Bat carcasses found in a crevice at the swarming site on Lüneburger Kalkberg in September 2021 (A) are very similar to those found on Segeberger Kalkberg in September 2020 (B). We recognize great similarities in the finds (several carcasses together, bite marks on the body, no bitten off skulls) and see this as evidence of predation by brown rats at Lüneburger Kalkberg.

individuals, usually subdivided into smaller, kin-related units

such as pairs, harems, or other unisexual clusters (Schweinfurth, 2020). The high human visitor numbers at both Kalkberg sites, together with associated food waste, create profitable urban "resource patches" for *R. norvegicus*. Accordingly, established colonies can be expected. The similarity between both sites makes is plausible that rat predation on swarming and hibernating bats occurs also at the Lüneburger Kalkberg.

3.3. Estimation of predation impact

Brown rat colonies in urban "resource patches'' such as refuse sites, basements or sheltered cavities generally comprise 20–60 individuals, with documented extremes from ≈ 15 to > 150 rats (Schweinfurth, 2020; Clapperton, 2006;). To assess the possible impact of predation by rats we treat ≈ 15 rats as a conservative lower-bound colony size. Using an average energy content of ≈ 45 kcal per bat, *M. nattereri* or *daubentonii,* (Kunz et al., 1998) and a daily maintenance requirement of ≈ 70 kcal per *R. norvegicus* (NRC: National Research Council US Subcommittee on Laboratory Animal Nutrition, 1995), a single rat would need to consume ~140 bats to meet its energetic demands over a 90-day bat hibernation period in the absence of alternative food. Extrapolating to the conservative colony size reported for urban "resource patches" (≈ 15–60 individuals; Schweinfurth, 2020) yields a potential removal of ~2100–8400 bats each winter. Even the minimal-colony scenario of 15 rats would eliminate ≈ 7 % of the ~30.000 bats overwintering at Segeberg.

This calculation deliberately considers an extreme scenario – a small rat population subsisting exclusively on bats – in order to illustrate the possible potential scale of the problem. Field data demonstrate that diets with high proportions of animal prey are feasible. For example, stomach analyses from 77 brown rats from a Tokyo fish market revealed 86 % fish, and a population on Miyake Island obtained 70 % of its diet from invertebrates and vertebrates (Yabe, 1979). Although bats are unlikely to constitute the entire winter food of brown rats, scenarios with substantial animal fractions are plausible; even moderate predation rates could impose appreciable additional pressure on large *Myotis* assemblages in urban mass-hibernacula. Our estimates are obviously a gross simplification, yet they highlight the potential for substantial population-level effects, particularly at mass hibernacula, which serve as critical refuges in temperate Europe and are afforded special conservation protection (Mitchell-Jones et al., 2007).

4. Discussion

Our observations document, for the first time, systematic predation by *R. norvegicus* on bats at urban hibernacula hosting several thousand individuals in Europe. This behavior was filmed at the Segeberger Kalkberg and evidence of predation by brown rats was found also at the Lüneburger Kalkberg.

While invasive rodent predation has been extensively studied on islands (Towns et al., 2006; Nance et al., 2023), evidence from continental ecosystems remains scarce. Our findings demonstrate that urban environments can replicate similar ecological dynamics, with invasive rodents exploiting high bat densities during critical life stages such as swarming and hibernation. At the Segeberger Kalkberg cave, we documented two distinct hunting strategies employed by rats: aerial interception of swarming bats and the capture of resting individuals. Although the 52 documented carcasses represent < 0.2 % of the hibernating population (~30.000 bats) before control measures were implemented, these observations demonstrate that *R. norvegicus* predation can add a measurable source of mortality. The findings from the Lüneburger Kalkberg, including carcass caches resembling those at the Segeberger Kalkberg, further support the suggestion that rats prey on bats at multiple urban sites.

Our observations also reveal remarkable manipulative abilities of *R. norvegicus* in natural settings. Rats skillfully used their vibrissae and forelimbs to detect and capture bats in total darkness, balancing on their tails when lunging. Such complex manipulative behaviors have been extensively described in laboratory studies (Sacrey et al., 2009), but direct observations of their application in wild predation events remain scarce.

The adaptability and opportunistic foraging behavior of *R. norvegicus* is well established in urban contexts (Aplin et al., 2003; Parsons et al., 2017), with dietary shifts reflecting resource availability (Feng and Himsworth, 2014). Our findings indicate that this behavioral plasticity extends to exploiting vulnerable prey such as hibernating bats, emphasizing the species' ecological versatility and potential threat to bat conservation. It should be noted that large bat assemblages can attract multiple predator guilds; in continental Europe, tawny owls (*Strix aluco*) and barn owls (*Tyto alba*) have been shown to prey on large numbers of hibernating or swarming bats at mass roosts (Lesiński et al., 2009; Sommer et al., 2009). Even small resident songbirds may exploit this resource: great tits (*Parus major*) in a Hungarian cave systematically searched for and consumed torpid common pipistrelles (*Pipistrellus pipistrellus*; Estók et al. 2009). When these avian predators occur together with mammalian hunters such as stone martens (*Martes foina*), raccoons (*Procyon lotor*), and domestic cats (*Felis catus*), the cumulative predation pressure on urban hibernacula can therefore be significantly higher than that of a single predator species such as the brown rat.

While documented cases of rodent predation on bats remain rare in continental Europe, isolated reports such as predation by wood mice, *Apodemus sylvaticus,* on hibernating bats in the Netherlands (Haarsma and Kaal, 2016) suggest that such interactions do occur beyond island ecosystems. More serious and better documented examples are known from islands, such as the decline of the New Zealand greater short-tailed bat *(Mystacina robusta)* due to rat predation (Towns et al., 2006) and the impact of rodents on the Mexican fishing bat *(Myotis vivesi)* (Samaniego-Herrera et al., 2011; Floyd et al., 2010). Both species are frequently spend time on the ground for hunting and roosting, presumably increasing their exposure to rodent predation.

Our observations also have important implications within a One Health framework, which emphasizes the interconnectedness of human, animal, and environmental health (Zinsstag et al., 2011). Understanding and addressing the complex interactions between

wildlife and invasive species is central to this holistic approach. Both bats and rats are recognized reservoirs for a wide variety of zoonotic pathogens, including coronaviruses and paramyxoviruses (Calisher et al., 2006; Gloza-Rausch et al., 2008; Drexler et al., 2012). While our study did not assess pathogen transmission directly, these predation events provide rare evidence of direct contact between two significant wildlife reservoirs in an urban setting, highlighting a potential interface for pathogen exchange. Such interactions may facilitate the spillover of bat-associated pathogens to rodents, potentially altering disease dynamics and expanding transmission opportunities to humans and domestic animals (Luis et al., 2013).

It is important to emphasize that our findings do not indicate an immediate zoonotic risk. However, they highlight a mechanism through which invasive rodent populations might contribute to the amplification and redistribution of pathogens within urban ecosystems. In this context, integrated rodent management should focus exclusively on invasive, non-native species - principally *R. norvegicus* - leaving native rodents unaffected. Targeted control of these invasive rats at key bat hibernacula would both safeguard vulnerable bat populations and reduce potential public-health risks, thereby aligning biodiversity-conservation goals with One-Health principles while upholding a 'do-no-harm' stance toward native fauna. In addition to protecting vulnerable bat populations from predation, these efforts may help mitigate opportunities for pathogen exchange at the wildlife-human interface.

Effective management of *R. norvegicus* populations at urban bat hibernacula may be important to mitigate potential conservation and public health risks. A comprehensive approach aligned with One Health principles could provide a proactive framework, as demonstrated in several urban rodent control programs. Reducing anthropogenic food sources is fundamental in controlling urban rat populations (Traweger et al., 2006). Urban green spaces often support high rat densities by providing abundant food and shelter (Cock et al., 2024). Therefore, the implementation of rodent-proof waste containers and an increased frequency of waste collection is essential, particularly in high-traffic tourist areas such as our study sites (Himsworth et al., 2013; Cock et al., 2024). Additionally, public awareness campaigns aimed at reducing food waste and discouraging the intentional feeding of wildlife can significantly decrease the attractiveness of urban environments to rats (Murray et al., 2024).

Urban greening initiatives, while beneficial for biodiversity, can inadvertently increase habitat suitability for rats (Cock et al., 2024). Targeted, habitat-sensitive maintenance of urban green spaces - e.g. pruning dense ground-level thickets immediately adjacent to waste bins or cave entrances while retaining canopy cover and varied vegetation structure elsewhere - can reduce rodent shelter sites for invasive *R. norvegicus* without sacrificing the habitat complexity that supports native birds, invertebrates, and other wildlife (Parsons et al., 2017; Lepczyk and Aronson, 2017; Cock et al., 2024). Thus, regular maintenance of urban green spaces is critical to prevent the establishment of stable rat populations (Cock et al., 2024).

Furthermore, straightforward infrastructure modifications can restrict rat access to bat hibernacula. For example, removing the black fabric that acted as a climbing aid at the Segeberg Kalkberg entrance eliminated predation around the light-barrier system. Additional measures – such as sealing foundation joints, blocking connections from caves to sewers and modernizing drainage systems - can prevent dispersal via sewers (Adrichem van et al., 2013). Active control should then be guided by a quantitative baseline of rat abundance: capture-mark-recapture grids, camera trap encounter rates or chew-card bite indices can clarify whether predation is driven by a few transient individuals or by a resident colony (Cavia et al., 2012; Nottingham et al., 2021; Mackenzie et al., 2022). Mechanical traps and, where legally permissible, strictly regulated rodenticides remain core tools, while integrated programs in Amsterdam and Rotterdam show that coupling waste management, public outreach, habitat modification and ongoing sewer maintenance can be highly effective (Adrichem van et al., 2013; Cock et al., 2024) Together, these measures can limit invasive-rat predation at urban hibernacula, reinforce bat-conservation objectives and reduce potential public health risks within a One-Health framework.

5. Conclusions

Our findings show the importance of bat conservation in urban landscapes. Mass hibernacula, which are essential habitats for temperate bat populations, may be threatened by invasive rodents. Our order-of-magnitude estimates suggest that predation could be effective at the population level and underline the need for targeted conservation measures. In practice, mitigation should focus on managing invasive rodents while safeguarding native fauna. Furthermore, our observations indicate a possible interface for pathogen exchange between two important wildlife reservoirs. Management of invasive rodents at important bat hibernation sites supports biodiversity conservation and reduces potential public health impacts as part of a One Health strategy. Further research is needed to quantify the ecological impact of rodent predation on bat populations. Our observations suggest that it should be investigated whether and how these interactions contribute to pathogen dynamics in urban ecosystems.

Ethics Statement

All observational studies were conducted under licenses LLUR_521_20180703 and H42L-22202-Fledermäuse-Ausnahme-Kalkberg&WEA-Projekte, issued by the Landesamt für Landwirtschaft, Umwelt und ländliche Räume Schleswig-Holstein and Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz. No animals were handled during this study, and all observations were conducted in accordance with local wildlife protection and conservation regulations.

CRediT authorship contribution statement

Mirjam Knörnschild: Writing – review & editing, Supervision, Validation. **Anja Bergmann:** Methodology, Data curation, Writing – review & editing, Investigation. **Florian Gloza-Rausch:** Writing – original draft, Validation, Project administration, Investigation, Formal analysis, Conceptualization, Writing – review & editing, Visualization, Resources, Methodology, Funding acquisition, Data

curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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