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Preventing zoonoses. Promoting biophilia

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Preventing zoonoses. Promoting biophilia

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Wildlife culling as a biophobic response to zoonotic disease risk: why we need a one health approach to risk communication

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Zoonoses – infectious diseases that are transmitted between people and other animals – are one of the foremost public health threats. Public health messaging is a critical tool for informing at-risk communities about zoonotic disease threats and effective mitigation measures. Unfortunately, when not carefully crafted, public health messaging can foster fear-based (biophobic) responses to wildlife that may carry zoonotic pathogens—enculturating fear, disgust, and other forms of aversion. In worst case scenarios, biophobia of zoonotic hosts can result in humans culling wildlife populations or destroying their habitat. To better understand how public health messaging can responsibly provide necessary information on zoonoses risks while also promoting an affinity (biophilia) for potential zoonotic pathogen hosts, we conducted a literature review to identify cases of zoonoses-initiated wildlife culls and evaluated patterns and trends. We found that culls are frequently of native wildlife species, rather than nonnative species, and often increase threats to human health rather than mitigate them. We further found that the cultural impetus behind culls is rarely evaluated or discussed in the literature. Clearly, more research is needed in this regard. Human, animal, and environmental health are intertwined, and thus zoonoses prevention and mitigation is best addressed through a One Health lens. There is a need for public health and conservation professionals to collaborate in the development of risk mitigation messaging that enculturates effective zoonoses preventative measures, including biodiversity conservation.

KEYWORDS

biodiversity, fear, messaging, public health, zoonoses

1 Introduction

Zoonoses – infectious diseases that are transmitted between people and non-human animals– are a driving force in human evolution and society (Ledger and Mitchell, 2022). As humans have expanded across the globe, increased to over eight billion in number (United States Census Bureau, 2024), and degraded ecological systems in the process of meeting societal demands, zoonotic disease outbreaks have also increased in frequency and severity (Debnath et al., 2021). At present, zoonoses lead to an estimated 2.5 billion cases of human illness and 2.7 million human deaths annually (Grace et al., 2012). While many zoonoses are transmitted to humans by domesticated animal hosts, most zoonotic pathogens are hosted by wildlife (Jones et al., 2008).

In contemporary culture, public understanding of zoonotic disease risk is largely based on information disseminated by public health agencies at local and national scales. These agencies have a mission to protect people. Typically, the goal of this public health messaging is to minimize the likelihood that zoonotic pathogens will be transmitted from wildlife or domesticated animals to people. For pathogens that have the potential for human-to-human spread, public health messaging also provides cautionary information and guidance (e.g., masking) to reduce the likelihood that an epidemic (localized outbreak) or pandemic (large-scale outbreak) will occur (e.g., CDC, 2024).

Undoubtedly, public health messaging aimed at zoonoses prevention safeguards human lives, livelihoods, and various socio-cultural norms. It can be successful in enculturating risk-reducing human behaviors, such as washing hands before meals. Public health messaging can thus also facilitate the adoption of new cultural norms that improve human welfare and security.

Despite the positive intent and impacts of public health messaging to prevent zoonoses outbreaks, risk communication can have drawbacks from a biodiversity conservation perspective. Risk communication typically includes information on which wildlife or domestic animal species may transmit respective diseases. In response to this information, people may develop adverse relationships to these species out of a sense of self-protection. This is particularly true when the diseases of concern can have crippling or fatal outcomes (Decker et al., 2012; MacFarlane and Rocha, 2020; Shapiro et al., 2021). Public health messaging can thereby facilitate biophobia – a reaction to biological organisms encompassing "dark emotions" such as fear, disgust, and aversion (Soga et al., 2023; Soga and Evans, 2024).

A wide range of negative attitudes and behaviors have been reported in response to zoonoses-based biophobia, including killing animals that may host pathogens and destroying wildlife habitats. Biophobia-induced wildlife culling (killing animals at the population level) is an extreme reaction to public health risk communication wherein fear or other dark emotions drive humans to attempt to reduce or eradicate wildlife populations that are known or believed to transmit a specific zoonotic disease. In addition to potentially adversely impacting animal welfare, this practice is problematic from at least three perspectives: 1) wildlife culling to mitigate zoonoses risk is rarely effective in reducing pathogen prevalence or transmission rates among wildlife hosts (Olival, 2016; Miguel et al., 2020; Viana et al., 2023); 2) the culling activity may increase transmission risk to humans (e.g., if carcasses are handled by hunters; Keatts et al., 2021); and 3) there may be adverse impacts on wildlife populations and ecosystems more broadly, particularly when native species are targeted (Asprilla-Aguilar et al., 2007; MacFarlane and Rocha, 2020; Shapiro et al., 2021). These unintended adverse consequences of public health messaging largely arise from the focus of this messaging on people without sufficient regard to how human health is dynamically intertwined with the health of animals and the natural environment.

In this Perspective, we provide a brief review of biophobia in the zoonoses risk mitigation context and report on case studies wherein populations of wildlife hosts have been culled or their habitat destroyed in response to zoonoses (S1). In two of these case studies, we examine the social drivers and messaging that impacted culling efforts (Boxes 1, 2). We conclude with a call for a One Health approach to zoonoses risk communication that simultaneously promotes public health and biodiversity conservation messaging for situations in which native wildlife are known or suspected to be zoonotic pathogen hosts. To protect human, animal, and ecological health, there is a need to educate stakeholders about zoonotic disease risk, enculturate effective zoonoses risk mitigation strategies, and foster a lasting affinity for the natural world.

2 Biophobia

"Biophobia" emerged conceptually as the antonym of "biophilia," defined by ecologist E.O. Wilson as "the innate tendency to focus on life and lifelike processes" (Wilson, 1984). Biophilia is believed to be largely inherent, but can also be learned (Barbiero, 2011). It has numerous positive impacts at the individual level, including stress reduction and positive social behaviors (Olivos-Jara et al., 2020). Biophilia among humans also benefits biodiversity conservation through increases in pro-environmental behaviors and support of pro-environmental policies (Soga et al., 2016; Alcock et al., 2020).

Although the common definition of biophobia is "fear of nature or a specific organism" (Correia and Mammola, 2024), the experience of biophobia can also include feelings of panic, disgust, or other aversive emotions (Castillo-Huitrón et al., 2020). Biophobia is both innate and learned (Correia and Mammola, 2024). As an evolutionary adaptation, biophobia among early humans was requisite for survival. Threats such as large predators, toxic plants or fungi, or venomous animals likely led to the evolution of behavioral and physiological survival responses in humans (Castillo-Huitrón et al., 2020; Patuano, 2020; Correia and Mammola, 2024).

As a learned response, biophobia can manifest at the individual or community level. Phobias may result from personal experiences or information conveyed by others. For example, young children exhibit fear of snakes less often than older children or adults (Souchet and Aubret, 2016). Biophobia may be a shared response in communities and cultural groups to real or perceived threats (Gish et al., 2024; Soga and Evans, 2024). Ultimately, biophobia

BOX 1 Case Study: Marburg Virus Disease in Egyptian Fruit Bats.

The Kitaka Cave in southern Uganda was mined for lead and gold beginning in the 1930s (Towner et al., 2009). In July through September 2007, four miners in Kitaka Cave were infected with Marburg Virus Disease (MVD), one of whom died from the disease (Towner et al., 2009; Amman et al., 2014). The mine was inhabited by a population of >100,000 Egyptian fruit bats (Towner et al., 2009). This species is the natural host of Marburg virus and Ravn virus, the etiologic agents of MVD. The Ugandan Ministry of Health closed access to the mine in response to the MVD infections. There was no risk-mitigation response, and miners were not financially compensated for their lost income (Towner et al., 2024). Disease researchers from the U.S. Centers for Disease Control and Prevention provided informal information to district health authorities and miners cautioning that the mine should not be entered without personal protective equipment, which was cost-prohibitive to the miners, and that culling the bats would likely have negative public health and ecological impacts (Towner et al., 2024). In 2008, the miners initiated a cull of the bats. Using reed barriers and fishing nets, they prevented bat egress from the cave, then sealed cave entrances with sticks and plastic (Amman et al., 2014). A pile of dead bats was found in the forest in August 2008, and by November 2008 the cave appeared to be fully void of bats (Amman et al., 2014). In October 2012, an outbreak of MVD occurred in Ibanda, a town approximately 20km from the Kitaka Cave. An etiological investigation found only one population of Egyptian fruit bats in the region, located in the repopulated Kitaka Cave. The population in the cave was estimated to include 1–5% of the population observed prior to the cull (Amman et al., 2014). Subsequent evaluations indicated seroprevalence of MARV and RAVV among the Egyptian fruit bats was 5% prior to the cull and 13% after the cull. While the ecological driver behind the increase cannot be certain, it may be attributed to increased movement and contact between animals that survived the cull with the large number of susceptible (disease-naïve) animals that repopulated the mine after the cull. The colonizing bats, exposed to the virus for the first time, could have had higher levels of titers and antibodies than animals that had been long-infected. This is particularly relevant to human health risk, as elevated antibody levels can lead to higher spillover rates (Amman et al., 2014).

leads to nature-avoidance behaviors and increases likelihood of supporting or participating in actions aimed at eliminating nature (Soga and Evans, 2024). Demonstrated by humans at the community level, biophobia can have devastating impacts on native wildlife populations and ecosystems. Unfortunately, biophobia and the impacts thereof are increasing in scale and magnitude (Soga and Evans, 2024). People living in urban and economically developed communities demonstrate greater levels of biophobia than those living in rural areas (Soga et al., 2023). As the proportion of humans living in urban areas is expanding, so too is the proportion of humans disconnected with nature (Castillo-Huitrón et al., 2020). Public levels of zoonoses biophobia appear to be also increasing in tandem with greater misinformation and media coverage (Decker et al., 2012), which is often poorly-crafted and inadequately contextualized (MacFarlane and Rocha, 2020).

Like other forms of biophobia, biophobic response to pathogens and parasites is both inherent and learned. Humans and other animals have evolved preventative and reactive responses to avoid pathogens and parasites (Hart and Hart, 2018; Sarabian et al., 2023). Given the increasing occurrence of zoonotic spillover, it is perhaps unsurprising that humans are developing biophobia toward zoonotic hosts. Yet, these fears are often unmerited, as public fear can be centered upon a perceived zoonotic host rather than a confirmed host and, in many circumstances, the collective fear of zoonotic hosts likely outweighs actual risk (MacFarlane and Rocha, 2020). For example, in the wake of the COVID-19 pandemic, public fear and animosity towards bats increased, largely due to the misconception that bats have been demonstrated to be the reservoir host of the virus (Lu et al., 2021; Sasse and Gramza, 2021) and lack of understanding that it is exposure to infected humans and the human environment, rather than animal hosts, that poses the greatest risk (Mehraeen et al., 2021). There have been calls by the Australian government to cull fruit bats in response to Hendra virus (Olival, 2016), despite the fact that it is habitat loss (Eby et al., 2023) that fundamentally drives the spillover of the deadly virus to humans.

3 Culling as zoonoses risk mitigation

Although a considerable amount of wildlife culling is likely done as a fear-based reactionary measure without consideration for the broader implications, the strategic culling of animals by authoritative bodies to mitigate zoonoses risk is generally thought

BOX 2 Case Study: Suspected SARS-CoV-2 in Bats.

In February 2020, Zhou et al. (2020) published their findings that the novel coronavirus, now known as SARS-CoV-2, was 96% identical at the whole-genome level to a bat coronavirus previously identified in horseshoe bats (*Rhinolophus affinis*). This finding suggested that SARS-CoV-2 may have originated in bats (Mallapaty, 2020), although to date the reservoir host has not been identified. Following these findings, misinformation and media coverage associating bats with the pandemic were commonplace (MacFarlane and Rocha, 2020) and, consequently, negative attitudes towards bats among the public were strengthened (Lu et al., 2021).

In March and April 2020 alone, bat culls were reported in Cuba, South America, Africa, and Asia. Citizens in Cuba (ADNCuba, 2020) and Peru (RTE News, 2020) were documented killing bats with fire. In Rajasthan, a state in northwestern India, local citizens killed approximately 200 wild bats (Goyal, 2020). In some countries, governments intervened to protect bats. The Peruvian National Service of Wild Forests and Fauna released a statement calling for citizens to halt these culls (RTE News, 2020), and the federal government of India extended legal protection to bats under the Indian Wildlife Act (Goyal, 2020). Conversely, some governments were actively involved in efforts to cull bats or destroy bat habitat. Rwandan government employees shot roosting straw-colored fruit bats (*Eidolon helvum*) with water cannons in an effort to drive them away from the Kigali, the capital city (Bittel, 2020).

In Indonesia, bat culls were encouraged and implemented by local governments. The government in Subang, a regent in western Java, circulated a letter to the public with instructions to mitigate spread of COVID-19. Among guidelines including canceling large events and public school operations, residents received instructions to kill bats (Farhan and Assifa, 2020). In Surakarta, a city in central Java known colloquially as Solo, the local government gassed and burned bats that had been captured for sale in a local live animal market (CNN Indonesia, 2020). To stop these efforts, The Research Center for Biology, Indonesian Institute of Sciences – the national scientific authority – partnered with local conservation organizations. Together, they sent a letter to the local government in Subang and developed a public education flier, which they shared via social media. The letter and flier outlined the environmental and economic benefits of bats, explained that the strain of SARS-CoV-2 hosted by bats in Indonesia was non-infectious to humans, and elucidated the futility of culling bats as a disease mitigation strategy. Within days of these efforts, the governments stopped culling bats (Sigit Wiantoro, Museum Zoologicum Bogoriense – BRIN, *pers. comm.*; Ellena Yusti, CRC 990 EFforTS, *pers. comm.*)

to be underlain by two key assumptions. The first assumption is that the transmission rate of a given pathogen (R_0) correlates with wildlife population size (Guyton and Brook, 2015). This assumption is relevant for some density-dependent pathogens, but transmission is often independent of population size or density. The etiologic agent of plague, *Yersinia pestis*, can persist in relatively small rodent populations, resulting in occasional and sporadic human epidemics (Keeling and Gilligan, 2000). Pathogen transmission rates can also be dependent upon frequency of specific behavioral interactions, such as those that are sexually transmitted or vector-borne (Miguel et al., 2020). The second assumption is that culling decreases population size (Guyton and Brook, 2015). This is a flawed assumption, as many wildlife species compensate for decreased population density through increased immigration or increased reproductive output (Myers et al., 2000). The documented stability of fox population sizes despite culls in varied spatial and temporal settings is a prime example (Baker et al., 2002; Comte et al., 2017; Jiguet, 2020).

Culling can, in some circumstances, be an effective disease mitigation strategy (Geering and Penrith, 2001; Prentice et al., 2019; Miguel et al., 2020). In the case of livestock or other captive animals, the number of animals can be determined, movement restricted, and interactions with other species limited. In these circumstances, preemptive (Tildesley et al., 2009) and test-based (Lu et al., 2008) culling have effectively reduced disease prevalence and transmission. In contrast, culling free-ranging wildlife poses a myriad of challenges. Wildlife behavior and population dynamics are beyond human control and often unpredictable. Culling efforts of wildlife populations have resulted in altered spatial distribution and home range size (Woodroffe et al., 2006; Viana et al., 2023), transition to nocturnal activity patterns (More et al., 2015), increased immigration (Beasley et al., 2013; Lieury et al., 2015), increased reproductive output (Myers et al., 2000), and altered population age and sex structure (Miguel et al., 2020), all of which can influence disease dynamics, including potentially increasing transmission risk. Most wildlife culls implemented to mitigate zoonoses risk have lacked efficacy evaluation, have been found to be ineffective, or have counterproductively increased pathogen prevalence or transmission (Olival, 2016; Viana et al., 2023). Tragically, many wildlife culls for zoonoses mitigation have resulted in adverse consequences for animal welfare, greater species vulnerability, and cascading ecological impacts (Guyton and Brook, 2015).

4 Culling case study findings

Our literature review methodology and case study summaries are located in Supplementary Table S1. The majority of culls to mitigate zoonotic risk are likely localized, unauthorized, and undocumented and therefore unreported in publicly transparent sources. However, we identified 35 case studies of culling in the scientific literature, all of which targeted mammal hosts. The culls aimed to mitigate risk of 12 pathogens and parasites: five viruses, four bacteria, and three parasites. Over half of cases were for rabies (n = 11) or bovine tuberculosis (n = 8). The majority of cases (n = 30) were conducted or authorized by governments or another authoritative body.

In reviewing these case studies, we noted that the explicit socio-cultural impetus behind culls is rarely evaluated or discussed. Reports of culls conducted by the public simply state that the cull was implemented in response to a particular zoonotic threat, but do not investigate the knowledge or motivation of those initiating the cull. For example, it cannot be determined why the miners of Kitaka Cave culled the resident bats (Box 1). Towner et al. (2024) reported that the miners shared frustration they were unable to access the mine for financial reasons. Motivations for the cull may have also included retaliation or fear for their personal safety. Reports of culls conducted by governments or other authoritative bodies also rarely elucidate decision-making criteria or discussion of alternative techniques. Most notably, it's clear that empirical evaluations of culls as a risk mitigation measure are not standard practice in these scenarios (i.e., the culls are not demonstratively science-based), nor are animal welfare or socio-cultural values evaluated via social science investigations. The motivation for many culls conducted both by the public and by authoritative bodies is, therefore, largely unjustified ("irrational") from the perspective of standard scientific procedure. Although likely held unconsciously in many cases, it is apparent that the fear that a wild animal is a threat to human survival and should therefore be destroyed, despite the cost to the animal's life, is a driving force for many culls, rather than rigorous risk management evaluation.

The fact that culling has proven to be largely ineffective at zoonoses mitigation further underscores the lack of objective decision criteria and likelihood of fear-based bias ("irrationality") in many circumstances. Efficacy of the zoonoses-initiated culls in our review ranged from ineffective or counterproductive (e.g., increase in pathogen prevalence reported by Comte et al., 2017), to mixed results [e.g., decrease in skunk density but increase in pathogen geographic distribution reported by Gunson et al. (1978) and Fehlner-Gardiner (2018)], to effective (e.g., decrease in pathogen prevalence and pathogen geographic containment reported by le Roex, 2014). The means by which culling efficacy was evaluated varied across studies. While it was unsurprising that efficacy of culls conducted by the public is rarely evaluated, over half (n = 16) of the culls by authoritative bodies did not include an evaluation of pathogen prevalence in the targeted host species in response to the cull. Studies that incorporated multiple evaluation criteria outlined important dynamics. For example, in a cull of rodents to mitigate threat of Lassa fever, Mariën et al. (2024) found the rodent population decreased, but the virus spillover rate to humans increased. Had this study included only an evaluation of rodent population density, the cull likely would have been deemed successful. Cases wherein culling was effective included unique cultural, geographic, or ecological circumstances. For example, Denmark has been free of rabies since 1982, partially credited to the cull of red foxes (*Vulpes vulpes*) in the 1960s–1980s, but also due to the geographic isolation of the country and continued rabies management in northern Germany (Aubert, 1999).

At least 20 of the 35 of the culls in our review were of native wildlife species. This is particularly concerning, as culling native species is likely more ecologically detrimental than culling nonnative species. Culls of native species in our review resulted in reduction in populations of keystone species (Cocozza and Alba, 1962), increased pathogen prevalence rates (Lee et al., 2018), and altered community assemblages (Bourne, 2007), all of which compromise the integrity and sustainability of local ecological communities.

5 Discussion

Harrison et al. (2010) and Miguel et al. (2020) outlined necessary conditions for disease-focused wildlife culling to be attempted, including a thorough understanding of the pathogen transmission cycle, known response of target wildlife populations to culling, economic efficacy of the cull, and support among stakeholders. While these guidelines provide important decision criteria at multiple levels, they do not identify the need for risk communication that avoids instilling a biophobic response. Likewise, the literature that we reviewed provides few examples of risk communication conducted in concert with biodiversity protection goals. To avoid future biophobia-driven culls, there is a clear need to develop a One Health approach to zoonoses risk communication.

The One Health High-Level Expert Panel defines One Health as, "an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and ecosystems," World Organisation for Animal Health (2021). Because zoonoses mitigation necessitates attentiveness to all three components of One Health, it is critical that zoonoses-focused public health messaging promotes zoonoses risk mitigation while also promoting biodiversity conservation and biophilia. There is, therefore, a need for collaboration between public health and biodiversity conservation practitioners, especially those working on the communication aspects of both fields. Studies of communication effectiveness indicate that messaging needs to be carefully crafted using consistent and clearly understood terminology (Shapiro et al., 2021), cautiously and intentionally communicated to the media (Tabbaa, 2010), and framed using evidence-based techniques to encourage pro-environmental behaviors (Jacobson et al., 2018; Niemiec et al., 2020). It is also important that "prevent zoonoses, promote biophilia" messaging is adapted to the local ecology, culture, language, and context (Reaser et al., 2024, this Research Topic).

A growing body of scientific literature demonstrates that wildlife culling to mitigate zoonotic risk is frequently ineffective at protecting human lives and can have dire impacts on native wildlife and ecological systems. Despite this, these culls continue, both as rogue endeavors by unauthorized citizens as well as coordinated efforts by local authorities. Although the culls may be well-intended to protect human lives, they are often futile efforts driven by biophobic response to zoonoses risk communication. There is an urgent need for scientific inquiry into the social drivers and decision criteria leading to these culls. Further, it is the responsibility of those in the public health and biodiversity communication fields to develop public health campaigns that provide guidance on effective zoonoses risk mitigation while simultaneously encouraging stewardship of the natural environment that is requisite for our survival.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Author contributions

CA: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. JR: Conceptualization, Funding acquisition, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2024.1488981/full#supplementary-material

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What's love got to do with it? A biophilia-based approach to zoonoses prevention through a conservation lens

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E.O. Wilson coined the term biophilia, defining it as an innate affinity to the natural world. The concept of nature connectedness is used in environmental psychology as a measure of feelings and self-perceptions of connectedness to nature. Researchers have found a wide variety of positive effects associated with nature connectedness, including better mental health and wellbeing, increased altruistic and cooperative behavior, and heightened empathy. When these feelings of empathy are directed toward nature and applied to conservation actions, they can overcome the effects of compassion collapse, a phenomenon observed to lower study participants willingness to engage in altruistic behavior when there are many or diffuse victims of a disaster. Biophilia is an important concept in conservation, but it has not been widely applied to zoonoses prevention. The public health community has often relied on fear-based (biophobic) messages, which can drive the very interactions they were intended to avoid (e.g., media reports of bat zoonoses leading to culling activities and destruction of bat habitat) and exacerbate the ecological drivers of spillover. Communication strategies rooted in biophilia may be more effective at generating empathy for both ecological and human communities, leading to greater willingness to leave zoonotic pathogen hosts and their habitats alone, further reducing spillover events and the ecological conditions that make spillover more likely. Given the intertwined nature of human and ecological health, it is critical that the conservation and public health communities speak in a unified voice.

KEYWORDS

biophilia, empathy, one health, zoonoses, communications

1 Introduction

There are few parables better known in ecological conservation than the time that conservationist Aldo Leopold killed a wolf. He was camped out on the rimrock of the western United States with a group of hunters eating lunch, watching what they took to be a doe fording the river below them. She climbed onto the bank and shook the water off her, and it was only then that they realized their error. The animal was not a deer at all. She was a wolf with a dozen pups, who sprang playfully out of the willows. In response, the men grabbed their guns and fired. The old wolf went down and at least one pup was injured. The hunters approached the mother. Imagine Aldo Leopold kneeling, watching the "fierce green fire dying in her eyes"—what he must have felt. He describes a deeply transformative realization of something already known to the wolf and to the mountain that the wolf inhabits: that the mountain relies on the wolf as much as the wolf is dependent upon the deer for its survival, and that their continued existence and health is contingent upon these relationships. What changed in Leopold—and what, through his work, has changed in the way we think about conservation—was an unfolding sense of empathy and love toward life and the processes necessary to sustain it. The term for this is biophilia.

The word biophilia is derived from Latin roots and translates literally to "love of life." Its origin is sometimes traced back to the psychoanalyst Erich Fromm, who used it to describe a "passionate love of life and all that is alive" (Fromm, 1964) in contrast with what he called necrophilia, a psychopathological orientation toward death and destructiveness. It was E.O. Wilson, however, who introduced the term into the conservation lexicon, seemingly independent of Fromm, in the context of his biophilia hypothesis. He defined biophilia as an innate propensity and affiliation toward life and lifelike processes, concluding that "to the degree that we come to understand other organisms, we will place a greater value on them, and on ourselves" (Wilson, 1984).

All ecology is about relationships. As the poet Robinson Jeffers asked, "What but the wolf's tooth whittled so fine/The fleet limbs of the antelope" (Jeffers, 1965)? Evolution is the outcome of relationships between a species or organism and its environment. That these relationships are the organizing principle of ecosystems is evident from food webs to chemical and physical exchanges to the spread of diseases. Human history is rife with examples demonstrating our propensity (especially in Western industrialized nations) to view ourselves as separate from the Earth system. It is a fundamental reality of human existence, however, that we must live embedded in relationship with our ecological communities, and that these relationships are integral to the things that make us human and allow our biological existence. Whether we know it or not, and whether we act upon that knowledge or not, we are members of these communities every bit as much as a brown bat or a cedar tree.

After watching the fire in the eye of dying wolf go out, Aldo Leopold wrote how something changed inside him. He said he learned to "think like a mountain." It was a moment of empathy and compassion for the dying wolf and, through it, an understanding of the way the wolf and the mountain rely on each other—the mountain providing habitat to the wolf, and the wolf regulating the deer population so that the mountain is not browsed to death—and of his own place within that matrix. This experience led him to profess a new environmental ethic, advocating for the expansion in scope of the communities we love from the familial and national into the ecological (Leopold, 1947). Through the connection he felt with the dying wolf, Aldo Leopold transformed himself from a man possessed by a fear-based (biophobic) impulse toward destruction into a man driven by a biophilic sensibility, from revulsion to the love of a species.

In this Perspective, I perform an investigation of biophilia through the lens of conservation psychology. I define biophilia as an experience of connectedness to nature, which leads to feelings of empathy, compassion, love, and other affinities toward the natural world. In keeping with the "Preventing Zoonoses. Promoting Biophilia" theme for this Research Topic, I discuss the ways in which typical public health communications may encourage biophobia, potentially leading to destructive acts that exacerbate the ecological drivers of zoonotic spillover. I examine the utility of a biophilic approach to zoonotic disease risk mitigation and discuss how public health and conservation messaging can be unified and made more effective through the perspective of biophilia.

2 The psychology of biophilia

Biophilia is actualized as a sense of connection to nature or, more deeply, the self as an aspect of nature—nature here being defined as the external physical world of flora, fauna, abiotic components and the flows of energy and nutrients through these interconnected systems. In environmental psychology, nature connectedness refers to subjective feelings of relatedness to the natural world (Martin et al., 2020). Numerous studies have shown that nature connectedness is associated with a number of positive effects on mental health and wellbeing (Grinde and Patil, 2009; Bratman et al., 2012; Capaldi et al., 2014; Kaplan Mintz et al., 2021; Pouso et al., 2021), early childhood development (Collado and Staats, 2016; Duron-Ramos et al., 2020; De La Osa et al., 2024), that it promotes prosociality, or cooperative and altruistic behaviors (Reddon and Durante, 2019; Pirchio et al., 2021; Gu et al., 2023), and generates pro-environmental behaviors and sentiments in children (Soga et al., 2016) and adults (Alcock et al., 2020; Barragan-Jason et al., 2022).

Mayer and Frantz (2004) developed a 14-point Connectedness to Nature scale (CNS), which assessed participants through a survey on their feelings of interrelatedness and belonging to nature. Models such as CNS (Martin and Czellar, 2016), the Extended Inclusion in Nature Scale, which uses spatial metaphors to assess participants feelings of self-inclusion in nature, and the Dispositional Empathy with Nature scale (Tam, 2013), have found predictable correlations between feelings of relatedness and belonging to the natural world with support for environmental and pro-conservation behaviors. Together, these models reveal how feelings of connectedness increase empathy, the role empathy plays in increasing pro-conservation attitudes, as well as how identity and behaviors are shaped (especially in childhood) through contact with nature (Mayer and Frantz, 2004).

Empathy is "an emotional state triggered by another's emotional state or situation, in which one feels what the other feels or would normally be expected to feel in his situation" (Hoffman, 2008). In human relationships empathy promotes prosocial behaviors and attitudes toward their human peers (Telle and Pfister, 2016). Empathy toward nature plays an important role in mediating pro-conservation behaviors (Mayer and Frantz, 2004; Tam, 2013), but the effect of empathy has its limits.

Large-scale disasters have been counterintuitively shown to lower compassionate and altruistic responses to suffering, a phenomenon called compassion collapse (Cameron, 2017). The effects of compassion collapse have been primarily studied in relation to human suffering, showing, for example, that donations decrease during disasters involving numerous unrelated victims versus an individual or a group that can be perceived as an individual unit, such as a family (Smith et al., 2013). Compassion, and the altruistic behavior associated with it, begins to collapse even after increasing the number of victims from just one to two (Cameron, 2017).

There are two primary explanations for why compassion collapse occurs: a) the capacity account, which suggests that compassion is a limited emotional resource that is depleted by exposure to mass suffering, and b) the motivational account, which suggests that compassion is a motivated response (i.e., a person chooses to act compassionately or not) and that exposure to mass suffering triggers an avoidance response, aimed at protecting oneself from the anticipated emotional cost of feeling compassion (Cameron, 2017).

While compassion collapse has primarily been studied in relation to human suffering, it may also hold true for conservation-oriented behaviors. Markowitz et al. (2013), found that across three different studies, compassion collapse played a predictable role in determining willingness of participants to devote both time and money to environmental causes. Participants took more compassionate action in response to the suffering of small populations of animals or singular animals, such as a named polar bear, than they did large populations. There was, however, one important caveat to these findings: they only held true among participants who did not self-identify as environmentalists. Markowitz et al. (2013) speculated that this may be because environmentalists perceived the animal subjects of the study as part of their in-group, therefore bypassing the motivated response to avoid the cost of compassion.

This suggests that compassion—and behaviors associated with compassion, altruism, and empathy—may be in part motivated by feelings of connectedness. Nature connectedness might lead to such a wide variety of prosocial and pro-environmental outcomes precisely because it situates people in broader communal relationships with places and other-than-human beings.

Currently, a number of compounding, large-scale anthropogenic factors are influencing ecological and climatic systems across the planet. These include, but are not limited to, mass extinction (Cowie et al., 2022), climate change (Intergovernmental Panel on Climate Change et al., 2023), habitat loss (Soulé et al., 2005), invasive species (Crystal-Ornelas and Lockwood, 2020), and the "trophic downgrading" of the planet through the extirpation and extinction of large-bodied, apex predators (Estes et al., 2011). In concert, these factors have degraded ecosystem resilience and may ultimately result in irreversible changes to the structure and functioning of ecosystems worldwide. The daily barrage of bad news about increases in the severity and frequency of wildfires, the spread of zoonotic diseases, or countless other signs of rapidly changing times may be a factor in our collective inaction due to compassion collapse.

3 Discussion: biophilia and zoonotic disease risk

Biophilia is seldom directly attributed to the success of any particular conservation project. However, building affinity and positive sentiment towards species—keystone attitudes of biophilia—is a common strategy in conservation work. Pride campaigns are a central principle in the work of Rare, which were first implanted in successful efforts to preserve the St. Lucia parrot (*Amazona versicolor*) through the use of a mascot (Butler et al., 2013). Other conservation success stories based on generating affinity and public sentiment include giant pandas (*Ailuropoda melanoleuca*; (Ma et al., 2016)), great white sharks (*Carcharodon carcharias*; (Apps et al., 2018)), and migratory birds (Wheeler and Bonfield, 2005). The strategy of generating biophilic sentiments towards species and habitats may be of similar benefit in addressing the intersection of conservation and zoonotic disease risk mitigation, where public messaging tends to focus more on aversion than affinity.

The One Health model provides an interdisciplinary framework for zoonoses prevention, but most implementations of it are relegated to research. In a series of 41 semi-structured interviews with One Health professionals, Pepin et al. (2024) found several significant barriers to operationalizing One Health principles, including a lack of cross-sector integration and a belief that One Health is nothing more than a "popular buzzword" that puts undue pressure on the public health sector to solve problems with established and effective solutions.

It is the siloed nature of the public health and conservation sectors that ultimately drive these perspectives. This disconnect may conceal ways in which today's public-health solutions—even those that are well-established and effective—might become tomorrow's conservation problem or vice versa. If we recognize that human, animal, and environmental health are intertwined, then working at cross-purposes in this way only serves to frustrate the achievement of long-term solutions in both sectors.

In contrast to biophilia, negative sentiments toward nature, manifesting as either a generalized aversion or as fear or revulsion directed at specific types of organisms (e.g., arachnophobia), are termed biophobia. When Aldo Leopold killed a wolf, he was participating in the biophobic culture of his time. Wolves have a long history of being demonized. In the United States, at least since the 1800s, wolves have been hazed, shot, tortured, and exterminated until, by the mid-twentieth century, wolves had either been extirpated or reduced (Lopez, 1979) into such low numbers that they were no longer effectively regulating deer and elk populations through predation, reducing landscape-level resilience (Eisenberg et al., 2013).

Biophobia can also be generated by public-health communications. For example, well-intentioned public-health messaging has suggested a link between bats and the COVID-19 pandemic, causing vitriol and suspicion to be heaped upon bat colonies and their habitats. More broadly, the COVID-19 pandemic exposed the public to a litany of news stories and public health warnings about the dangers of disease spillover through wildlife trade and "wet markets" (Aguirre et al., 2020; MacFarlane and Rocha, 2020; Lin et al., 2021), contributing to increased biophobic behaviors (Soga et al., 2021).

Bats are a reservoir for a number of pathogens deemed to be of high concern by the World Health Organization, including henipiviruses, filoviruses, and coronaviruses (Ruiz-Aravena et al., 2022), such as SARS-CoV-2, which causes COVID-19. There are legitimate reasons for people to adopt avoidant behaviors to minimize the risk of exposure to pathogens shed by infected wildlife. However, when this avoidance is rooted in biophobia, it may create a recursive feedback loop in which aversion leads to feelings of disconnection, leading to a loss of familiarity and knowledge of nature and thus greater avoidance or even persecution of bats to annihilate the fear trigger. This vicious cycle of biophobia could lead to or contribute to decreased motivation and willingness to engage in conservation actions that actually reduce zoonoses outbreak risk (Soga et al., 2023).

Moreover, these biophobic responses may generate the opposite response than intended, such as in Cuba, South America, Africa, and Asia, where media reports linking bats and COVID-19 drove local citizens to participate in culls, or an Indonesia where public health guidance explicitly asks residents to kill bats (Anderson and Reaser, 2024). These culls not only resulted in the death of bats and destruction of bat habitat but increased the public's exposure to them and their habitats (Anderson and Reaser, 2024).

The destruction of bats and bat colonies increased internationally during the pandemic (Soga et al., 2023). Ironically, such actions can have the unintended effect of increasing human-bat conflicts by forcing bat populations to rely on human infrastructure, creating more opportunities for spillover events (Frick et al., 2020). Loss of biodiversity and the loss of functional diversity through land-use changes (Platto et al., 2021; One Health High-Level Expert Panel et al., 2023), such as conversion of forest to agriculture and construction of human infrastructure (White and Razgour, 2020; Plowright et al., 2021; Marie and Gordon, 2023) can all significantly increase zoonotic pathogen spillover (Reaser et al., 2021), particularly in instances that allow small-bodied mammals (e.g., bats) to continue to thrive in the absence of dedicated habitat, increasing the potential for human-wildlife interactions (Glidden et al., 2021).

While nature exposure may lead to either biophilia or biophobia (Figure 1), depending on the context of the exposure, the feedback loop created by disconnection and aversion is a major barrier to generating biophilic sentiments. This may particularly be a problem among populations who live largely disconnected from the natural world, such as those in cities or whose wealth insulates them from the environment. Direct nature exposure, which may lead to biophilic sentiments, typically must be chosen. However, educational opportunities to develop natural intelligence (Barbiero, 2018), social-media marketing campaigns (Reaser et al., 2024), and art (Beaumont, 2024) all provide opportunities for reaching nature averse demographics.

But this raises an additional, vital question: how do we encourage nature connection and empathy in situations that require communications about disease risk, resulting in cautious behavior, without simultaneously generating biophobia and all of its negative consequences? In the public health field, human health is naturally prioritized, and public health officials may lack the ecological education needed to ensure that human health communications do not cause greater environmental harm. A One Health approach to zoonotic disease risk mitigation takes into account the interconnectedness of human, animal, and environmental health and acknowledges, for instance, that the health of bats and bat habitat is directly tied into the health of human communities. It is imperative that our models of disease risk mitigation include broader conservation objectives to reduce disruption of species and habitats that may harbor known or unknown diseases. Fostering sentiments of biophilia and the conservation behaviors that biophilia promotes should a priority in any One Health approach to zoonotic disease risk mitigation.

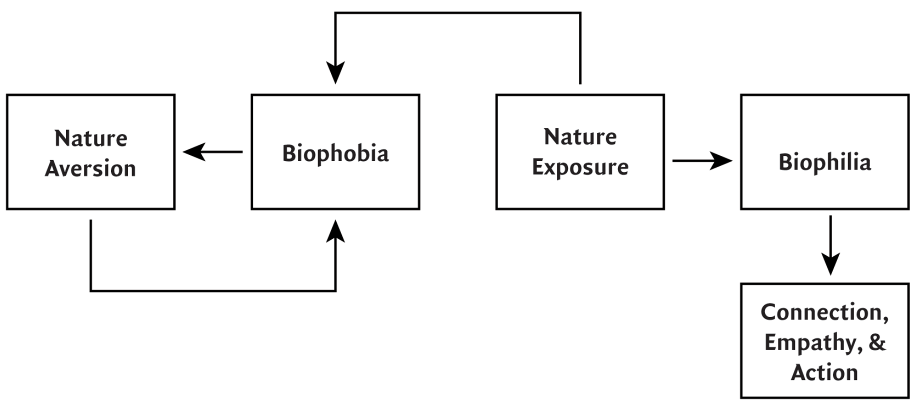

FIGURE 1
A conceptual framework of biophilia and biophobia. The arrows represent the development of sentiments and affinities as a result of nature exposure, leading to either 1) biophobia and nature aversion, potentially creating a vicious cycle (Soga et al., 2023), or 2) biophilia and nature connection, empathy, and action.

This same dilemma plays out frequently in conservation. For example, sentiments of biophilia may drive people to visit US National Parks. Yellowstone National Park hosted 4.5 million visitors in 2023 (US National Park Service, 2024). However, public use of these parks require infrastructure, such as buildings, roads, trails, and other land-use changes, which may result in loss of landscape connectivity, suppressed fire regimes, erosion, and changes to animal behavior, such as predator-prey dynamics, which may have wide-spread consequences within local food webs (Eisenberg et al., 2013). Perturbations such as these potentially alter ecosystems to an extent that they may function less resiliently than the unaltered predecessor ecosystem. Additionally, wildlife encounters in public parks can often be fatal to visitors. Without vigilant management of such a system, it is as possible to love nature to death than it is to fear it to death. The public health sector could draw on conservation messaging as a model in striking an appropriate balance between generating biophilia and risk-averse behavior.

The public health community is right to be concerned that fostering an affiliation between bats and humans, or any species at risk of spreading zoonotic pathogens, may drive an increase in interactions with pathogen hosts. But spreading biophobia can demonstrably have the same effect. Fear and affiliation are both drivers of interaction. Biophilia is more than mere affiliation, though. It is an active relationship in which a person comes to recognize themselves as part of the natural world, resulting in deeper empathy—a feeling of connectedness between the self and other—for natural systems and the organisms that compose them. This has the benefit of promoting both prosocial and pro-conservation behaviors, which may drive people to consider both the ecological impacts and the human health impacts of their actions.

One Health provides a framework for interdisciplinary engagement between the conservation and public health communities, but in practice their messaging remains fragmented, leading to confused priorities and competing messages. Ultimately, the public health and conservation communities want the same thing: a happier and healthier world. A coordinated communication strategy designed to meet both public health and conservation objectives could be a powerful and effective tool for mitigating zoonotic risk. Messaging rooted in biophilic empathy and oriented to the wellbeing of both the human and non-human communities could effectively encourage people to love and respect wildlife by leaving them alone.

Aldo Leopold recognized that wolves and the mountain where the wolves reside depend upon each other for their existence. He urged people to "think like a mountain," meaning to take the wider context into account. Similarly, a vision unified by biophilic sentiments and the understanding that environmental health and human health are dependent upon each other might act as the bridge between these silos. Leopold came out of his experience, articulating a Land Ethic that declared, "A thing is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it tends otherwise" (Leopold, 1947). This same ethic of biophilia, recognizing that humans are part of the biotic community, might serve as well to guide communications at the interface of conservation and public health. We might adopt it before we watch some other fierce green fire in the world go out.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

JRK: Conceptualization, Investigation, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Ecological-based insights into bat populations in the Yucatán Peninsula under a One Health approach: coexistence or biophobia

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The Yucatán Peninsula (YP) is home to approximately 60 bat species with differing feeding strategists that, collectively, are fundamental for the health of tropical forests. During the SARS-CoV-2 pandemic, biophobic (aversive) responses towards bats were recorded in urban and rural areas of the YP, making evident the need to monitor bat diversity, investigate species' biology (e.g., microbiome) and, perhaps most importantly, conduct educational activities that foster an affinity for bats. We designed a multi-scale effort to characterize bat populations and their gut microbiome in urban (Mérida), agricultural (Tizimín), and conserved (Calakmul) landscapes of the YP, while conducting outreach activities to promote biophilic responses. In general, children showed positive responses toward bats, recognizing that they are important parts of their environment. A total of 308 bats from 18 species were sampled; frugivorous species were the most abundant guild (93%), represented mainly by *Artibeus jamaicensis* and *Artibeus lituratus*, followed by insectivorous species. Conserved and agricultural landscapes harbored 11 and 16 bat species respectively, both with higher diversity than the suburban areas (eight species). Findings suggest that land use differences in the YP are a factor affecting bat diversity, as well as bat microbiome diversity. Gut microbiome was mainly composed of Pseudomonadota, Bacillota and Actinobacterota (>90%), and abundant bacterial families included *Enterobacteriaceae*, *Staphylococcaceae* and *Streptococcaceae*.

Our results have set the baseline for zoonotic disease screening and prevention in the YP, highlighting the importance of coexistence with bats given their key role in maintaining the health of ecosystems.

KEYWORDS

Artibeus jamaicensis, *Artibeus lituratus*, bats, biophilia, habitat fragmentation, microbiome, One Health, Yucatán Peninsula

1 Introduction

Bats are keystone species in tropical forests. They provide numerous ecosystem services beneficial to human well-being, such as seed dispersal, pollination, and insect control (Hougner et al., 2006; Kasso and Balakrishnan, 2013; Gannon et al., 2016; Ramirez-Francel et al., 2022). Nonetheless, effectively communicating these benefits to the human communities where bats are distributed, including policy makers and other stakeholders, remains challenging. Misconceptions and the lack of knowledge about bats have likely led to an underestimation of the ecological roles of bats and their significance to human lives and livelihoods (Kasso and Balakrishnan, 2013; Medellin et al., 2017; Ramirez-Francel et al., 2022).

In México, around 142 species of bats have been reported, approximately 60 of which inhabit the Yucatán Peninsula (YP) (Sosa-Escalante et al., 2013; Gaona et al., 2024). For the Maya people, who have dwelled in this region for the past 4,000 years, bats represent an important symbol as messengers of the dead. *Camazotz*, the vampire bat god, represents death and annihilates dying men on their way to the Underworld (Sieradzki and Mikkola, 2022). Cultural beliefs that associate bats with evil spirits, largely because of the animals' nocturnal nature, foster fear, explicitly 'chiroptophobia' (Sieradzki and Mikkola, 2022). Further exacerbating this fear, some bat species are natural reservoirs of viruses that can cause infectious diseases in humans, including Marburg, Nipah, Hendra, Ebola, influenza, rabies, Middle East (MERS) and severe acute respiratory syndrome coronaviruses (SARS-CoV-2) (Donaldson et al., 2010; Letko et al., 2020). Fear of bats and the misunderstanding of their ecological importance increased during and after the COVID-19 pandemic (Lu et al., 2021). Chiroptophobia induces biophobic (biological aversive) responses that challenge human coexistence with bats, hindering efforts to conserve their diversity and habitat globally (Sieradzki and Mikkola, 2022), consequently threatening the services bats provide.

Pathogens (disease-causing microbes) have also been identified in a diversity of wild animals (Donaldson et al., 2010; Bai et al., 2015; Bolatti et al., 2022). The natural transmission of zoonotic pathogens (those passed from fauna to humans) is called spillover (Jones et al., 2009; Saba-Villarroel et al., 2023). The rising number and magnitude of the emergence of zoonotic diseases are closely related to the ongoing socioeconomic and ecological changes associated with landscape modification, which forces wildlife into closer contact with humans and domestic animals, thereby facilitating pathogen (Jones et al., 2009; Federici et al., 2022; Sánchez-Soto et al., 2024). Urbanization and agriculture intensification, driven by human growth and affluence, are undoubtedly one of the main factors increasing the risk of zoonotic diseases (Jones et al., 2013). Disease-causing bacteria (e.g. *Leptospira, Rickettsia, Bartonella, Staphylococcus, Anaplasma*) have been detected in some bat species (Stuckey et al., 2017; Lugo-Caballero et al., 2021; Torres-Castro et al., 2020 and Torres-Castro et al., 2021; Federici et al., 2022) as common components of their microbiome (Federici et al., 2022). A growing body of research has shown that the microbiome responds to land-use and environmental changes, particularly where such changes lead to altered food resources (Amato et al., 2013; Barelli et al., 2015). Considering the zoonotic pathogens found in the microbiome of wild animals, recent studies have emphasized the importance of preserving their habitat from anthropogenic activities to minimize the spillover of potential infectious diseases (Federici et al., 2022).

The YP in México, like many other tropical regions, has a long history of landscape modification by human activities, which have failed to appropriately manage tropical forests and their biodiversity (García-Frapolli et al., 2007). Such land modification started during the development of the Mayan civilization (2,000 BCE–), followed by the prolific henequen production of the 19th century, until the current accelerated urbanization and expansion of economic activities in the region (Gómez-Pompa and Kaus, 1999; González-Iturbe et al., 2002). Specifically, regarding the three states that constitute the YP in México (Figure 1), urbanization and tourism mainly affect the coasts of Quintana Roo, while agriculture and livestock dominate the deforestation trends in Yucatán and Campeche, as a result of recent agricultural intensification policies (Ellis et al., 2017; Špirić et al., 2022). The YP loses over 280,000 ha of tropical forests every year (CCMSS, México 2024), thus under the current social and economic development model, biodiversity and ecosystem health will continue to be threatened (García-Frapolli et al., 2007).

Information regarding biodiversity, especially bat ecology and the role of bats in providing essential ecosystem services, can enhance opportunities to promote biophilia (biological affinity), particularly within the communities where bats are distributed. This can in turn aid in the development of conservation strategies and,

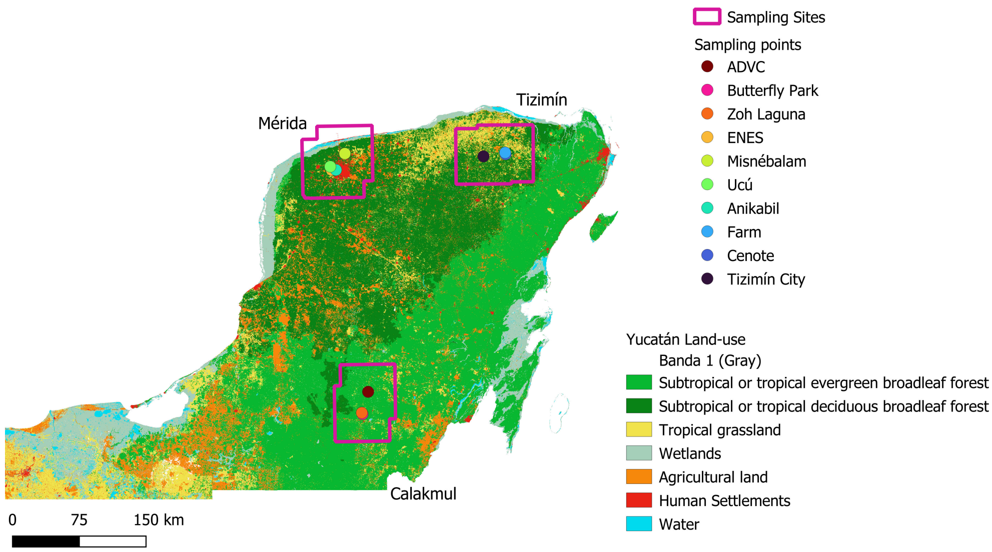

FIGURE 1
Sampling sites in the Yucatán Peninsula, México. Urban, agricultural and conserved landscapes according to the predominant land use correspond to Mérida, Tizimín and Calakmul municipalities. Sampling site shapes were generated with a buffer of 30 km that correspond to the average dispersal of sampled bat species. Source: Map modified with permission from INEGI, México (2020) land use and vegetation map, 2021.

concurrently, in actions that favor insect control. By promoting a biophilic perspective that fosters human-wildlife coexistence, it is possible to build a future where people and nature thrive together (Hougner et al., 2006; Tidball, 2012). Working with local communities is fundamental for conservation of wildlife and natural habitats. We became particularly conscious during the CoVID-19 pandemic that negative perceptions were growing towards bats. To promote bat conservation, we thus paired field work with a pilot program to promote biophilic responses to bats through outreach activities, giving educational talks in primary schools in the localities where we did sampling. Public outreach and the dissemination of scientific knowledge are critical to the promotion of conservation and the implementation of strategies that build towards a sustainable future. To this end, the project objectives we report on in this paper were to 1) perform educational intervention intended to cultivate positive feelings toward bats in school-aged children (5-11 years old); 2) assess the perception of bats in the children who participated in this pilot program; and at the same time 3) analyze bat diversity and microbiome across three landscapes (urban, agricultural and conserved) to produce locally relevant data for integration into further education efforts. Our analyses included screening for bacterial taxa and Betacoronavirus (β-CoV) that may pose potential threats to public health.

2 Materials and methods

2.1 Study region and sampling sites

The YP in southeastern México is characterized by a tropical warm and subhumid climate with an average annual temperature of 22°C-26°C and 800-1500 mm of rainfall (Vidal-Zepeda, 1990). The flat and low land relief is in the range of 0-250 m above sea level with a bedrock dominated by limestone (García-Rejon et al., 2008). Native vegetation in the most southern region is composed of tropical and subtropical evergreen high rainforests, characterized by a highly diverse floristic composition. Towards Campeche, Quintana Roo, and the south of the state of Yucatán, the vegetation is dominated by medium forest, semi-evergreen and sub deciduous forest. The northwestern region, including a large area of Yucatán, a small extension of Campeche, and dispersed along the Quintana Roo coast, is mostly covered by low deciduous and sub deciduous forests. The rocky and shallow soils of low forest result in a floristically and structurally simpler composition (Islebe et al., 2015).

The three study regions encompassed urban, agricultural and conserved landscapes (Figure 1). The urban region was located in the city of Mérida (population ~1,008,000), including the suburban communities of Ucú and Caucel. The agricultural region (ecotone) was located in Tizimín (population ~80,672) and the conserved region was located in the Calakmul Biosphere Reserve (population ~31,714), which harbors the largest continuous tropical forest cover in the Americas, after the Amazon (INEGI, México 2020).

2.2 Perception of bats in the Yucatán Peninsula

The SARS-CoV-2 pandemic evidenced the need to communicate the importance of bats globally because it was apparent that some people thought bats where to blame (Burki, 2020). As part of this effort, we worked with children (5-11 years old) in the localities of Mérida, Tizimín and Calakmul (Figure 1) during our bat sampling field work. This approach included informative talks in local elementary and preschools using teaching and game materials (i.e.

coloring masks/mandalas, paper sheets, crayons, game boards, infographic material showing myths and truths of bats). We displayed a mist net to show how field work is performed. Talks focused on bat diversity, morphological attributes, behavior, feeding habits, common beliefs, and the environmental services bats provide. Importantly, information given during the talks, as well as the games and teaching materials, were prepared and presented in accordance to the school level of the children in each school (see Table 1 for each school region, number of children participating and school level, and activities). After the talks, a basic questionnaire was distributed to all the children to assess the children's knowledge and perception towards bats (Supplementary Material S1). We highlighted the relevance of bats for humans' lives and provided basic recommendations (e.g., not handling bats and avoiding disturbing the animals and their shelters by any means). Respect for wildlife was instilled and we used inclusive language with respect for cultural and gender diversities. The complete bat perception and environmental education strategy is described in Supplementary Material S2. Schools approved, permitted, and supervised the talks, the general perception survey, and the teaching and game materials used. Additionally, we conducted a review of news articles and reports on biophilic or biophobic actions towards bats in the YP, before, during, and after the SARS-CoV-2 pandemic. The publication source, date, location, bat species involved, action on bats, and the motives were recorded (see Supplementary Material S3).

2.3 Sampling protocol

Bats were sampled following the guidelines of the American Society of Mammalogists for capture, handling, and welfare for wild mammals (Gannon and Sikes, 2007; Gardner, 1979). We set three mist nets during seven consecutive nights (19:00-01:00h), in each landscape during the dry (November 2021 and March 2022) and rainy (May 2022) seasons. Bats were placed in sterile plastic bags with ventilation until they defecated. Fecal samples were collected using sterile gloves and placed in empty and sterilized Eppendorf tubes (1.5 ml). All samples were frozen in liquid nitrogen until processing in the laboratory. Anal and oral swabs were taken using sterile applicators, stored in cryogenic tubes with RNA later (500µls) and preserved in liquid nitrogen. Standard measurements such as body and forearm length, weight, gender, age (adult or young by checking wing bone ossification), and females as lactating or pregnant, were recorded for all captured bats (Anthony, 1988; Jones et al., 1996). All sampling was done under collector permit SGPA/DGVS/07572/2.

2.4 DNA extraction

DNA extractions from fecal samples were performed with the QIAamp PowerFecal Kit (Qiagen, Valencia, CA) following the manufacturer's instructions. To increase DNA yield we concentrated DNA with a 3M sodium acetate (10%) precipitation resuspended in 30 µL of molecular grade water and stored at -20°C until PCR amplification. Additionally, total nucleic acids were extracted from anal and oral swabs for viral analysis following the MagNA Pure DNA and Viral NA small volume protocol using a MagNAPure DNA instrument (Roche) at the Institute of Virology, Charité, Universitätsmedizin Berlin.

2.5 Gene amplification and sequencing

Fecal DNA samples were PCR amplified with universal bacterial/archaeal primers 515F/806R (16S rRNA hypervariable region V4) following the procedures reported by Apprill et al. (2015). PCR reactions (25 µl) contained 2-6 ng of total DNA, 2.5 µl Takara ExTaq PCR buffer 10X, 2 µl Takara dNTP mix (2.5 mM), 0.7 µl bovine serum albumin (BSA, 20 mg ml-1), 1 µl primers (10 µM), 0.125 µl Takara Ex Taq DNA Polymerase (5 U µl-1; TaKaRa, Shiga, Japan) and nuclease free-water. Samples were amplified in triplicate using a PCR protocol including an initial denaturalization step at 95°C (3 min), followed by 35 cycles of 95°C (30 s), 52°C (40 s) and 72°C (90 s), adding a 12 min final extension at 72°C. Triplicates were pooled and purified using the SPRI magnetic bead, AgencourtAMPure XP PCR purification protocol (Beckman Coulter, Brea, CA, USA). The purified 16S rRNA fragments (~20 ng per sample) were sequenced on an Illumina MiSeq platform (Yale Center for Genome Analysis, CT, USA), generating ~250 bp paired end reads. The sequence data are available in the NCBI BioProject PRJNA1153560.

Anal and oral nucleic acid samples were analyzed for β-CoV following a PCR approach. β-CoV RNA was amplified with a hemi nested PCR method (Annan et al., 2013) using primers Pan2cRdRP-FWD and Reverse (10 µM). First round reactions had 12.5µls final volume, BSA (1 mg/ml), MgSO4 (50mM) with an initial reverse transcription of 50°C;C for 20 min, followed by an initial denaturation of 95°C; 3 min and 20X of 94°C; 15 sec, 60°C; 15 sec and 72°C; 30 sec; 30X 95°C 15sec, 50°C; 15 sec, 72°C; 30 sec with a touchdown of -0.5°C;C per cycle. The second round PCR included 1µl of the first-round product and primers pan2cRdRp-FWD and Rnest (10µM) with the same amplification protocol in 25 µl volume, MgCl2 (50mM), dNTP (10mM each). All PCR reactions were done

TABLE 1 Local rural communities where bat perception was surveyed in the Yucatán Peninsula.

Locality	Site	Participants	NP/NQ	Activity
Mérida, Ucú	Elementary School Felipe Alcocer Castillo	3° and 4° grade	70/4	Talk, questionnaire, teaching materials, games, Mist net.
Mérida, Ucú	Kindergarden Nezahualcóyotl	preschool	30/0	Talk, teaching materials, games, Mist net.
Tizimín	Elementary School Luis Álvarez Barret	3° and 4° grade	89/33	Talk, questionnaire, teaching materials, games, Mist net.
Calakmul	Elementary School Hector Perez Martinez	2°, 3°, 4° and 5° grade	150/27	Talk, questionnaire, teaching materials, games, Mist net.

NP, number of participants; NQ, number of questionnaires obtained.

with the SuperScript™ III One-Step RT-PCR System with Platinum™ Taq High Fidelity DNA Polymerase (Invitrogen). Amplicons (398-bp) were verified with agarose gel-electrophoresis and Sanger sequencing, but no further analysis was performed since no positive sequences were detected.

2.6 Microbiome bioinformatics and data analyses

We used fastp 0.23.2 (Chen et al., 2018) for quality control of the sequencing reads in fastq format and QIIME2 qiime2-amplicon-2023.9 (Bolyen et al., 2019) for quality processing of sequences. Sequence data were denoised with DADA2 and clustered by amplicon sequence variants (ASVs) (Callahan et al., 2016) with the q2-dada2 plugin. All ASVs were aligned with MAFF (Katoh et al., 2002) with the complement q2-alignment, which were used to construct a phylogenetic tree with fasttree2 (Price et al., 2010) and the q2-phylogeny plugin. Taxonomy was assigned to ASVs using the SILVA 138 database (Quast et al., 2013). Finally, we removed all sequences classified as Eukaryote or unclassified at the phylum level in the R programming environment (R Core Team, 2024) and filC; tered the samples between the 25th and 75th quartiles based on the frequency and type of feeding.

We used the 'tidyverse' package (Wickham et al., 2019) in R for data manipulation and visualization, 'qiime2R' (Bisanz, 2018) for integration of results coming from QIIME 2, 'phyloseq' (McMurdie and Holmes, 2013) for analysis of amplicon sequencing data and 'microbiome' (Lahti and Shetty, 2019) to perform biodiversity-specific analyses from a subsampling of 200,000 sequences per sample. Beta-diversity was tested on Unifrac metrics through the PERMANOVA model implemented in the 'adonis' function of the vegan package in R. Graphics for data analysis were elaborated in 'ggplot2' (Wickham, 2009).

2.7 Pathogenic bacterial survey

Sequence identification and analysis of pathogenic bacteria followed a meticulous process. We aimed to identify ASVs related at the family level to the most abundant bacterial families with known pathogens, which in this study were represented by Clostridiaceae, Mycoplasmataceae, Staphylococcaceae and Streptococcaceae, and at the order level to Enterobacterales, Rhizobiales, Rickettsiales and Xanthomonadales. We conducted restrictive blast searches (Altschul et al., 1990) against a specialized pathogen database (Yang et al., 2023) to identify sequences similar to organisms of epidemiological interest. The sequences with the best hits were extracted for further analysis. These selected sequences were then clustered with cd-hit (Li and Godzik, 2006), aligned from the V4 16S rRNA region with MAFFT, and phylogenies were constructed using FastTree. We used FigTree software (http://tree.bio.ed.ac.uk/software/figtree/) to visually represent the phylogenetic relationships between sequences. Finally, an analysis of each ASV that clustered to a known zoonotic bacterial agent was performed for each bat species per study area.

3 Results

3.1 School children survey

The number of children participating in the talks and in the drawing and gaming activities in each school are indicated in Table 1 (see Supplementary Material S1 for detailed information). We provided the questionnaire to all the children and obtained responses from 73; the total number of drawings was 94 (data not shown). The survey aimed to explore the children's knowledge and positive or negative feelings toward bats after the talks we presented; we found that most (96%, 70/73) are familiar with bats and knowledgeable of their feeding strategies and habits (Supplementary Material S1). Interestingly, all children answering the questionnaire from Calakmul, the most conserved landscape, had a 100% positive perception of bats. Most children (78%) from agricultural Tizimín considered bats to be beneficial for ecosystems. Drawings showed a positive trend of the children's perception and feelings towards bats after the educational intervention (Figure 2).

Our review of news articles and reports on biophilic actions toward bats in the YP revealed that few biophobic incidents have been recorded in the YP, with only 10 news reports since 2006 (Supplementary Material S3). During the SARS-CoV-2 pandemic, three incidents were reported of direct attacks from people to bat colonies, whereas previous to the pandemic, four reports occurred related to rabies (SENASICA, México, 2024), and the rest had no direct cause.

3.2 Bat diversity

A total of 308 bats representing three families (Phyllostomidae, Vespertilionidae, and Mormoopidae), and 18 species were sampled, 42.2% of which (130/308) were found in the most conserved landscape (Calakmul), 31.5% (97/308) in the agricultural (Tizimín) and 26.3% (81/308) in the urbanized landscapes (Mérida suburbs) (Figure 3). The number of bat species and diversity (Shannon diversity index) were similar in all localities (Figure 3; Supplementary Material S4). A total of six bats species, four frugivorous *Artibeus jamaicensis*, *A. lituratus*, *Glossophaga soricina* and *Sturnira parvidens* and two insectivorous *Pteronotus mesoamericanus* and *Rhogeessa aeneus*, were observed in the three landscapes (conserved, agricultural and urban). Frugivorous strategists accounted for 93% of all observations (Figure 3), while the insectivorous strategists accounted for only 5%. Fruit eaters were mostly represented by *A. jamaicensis*, the dominant bat species (35%, 109/308) in all the sampling settings. Other frugivorous bats including *A. lituratus* (18%, 55/308), *G. soricina* (13%, 48/308), *Carollia sowelli* (10%, 32/308), *Dermanura phaeotis* (7.5%, 23/308) and *S. parvidens* (7.5%, 17/308) were relatively abundant in different landscapes (Figure 3). *A. lituratus* was more abundant in the agricultural and conserved landscapes, *C. sowelli* and *D. phaeotis* were better represented in conserved areas, while *G. soricina* showed higher abundances in the urbanized and *S. parvidens* in the agricultural landscapes. The insectivorous bats (15 individuals) were mostly observed in the agricultural landscape. Carnivorous

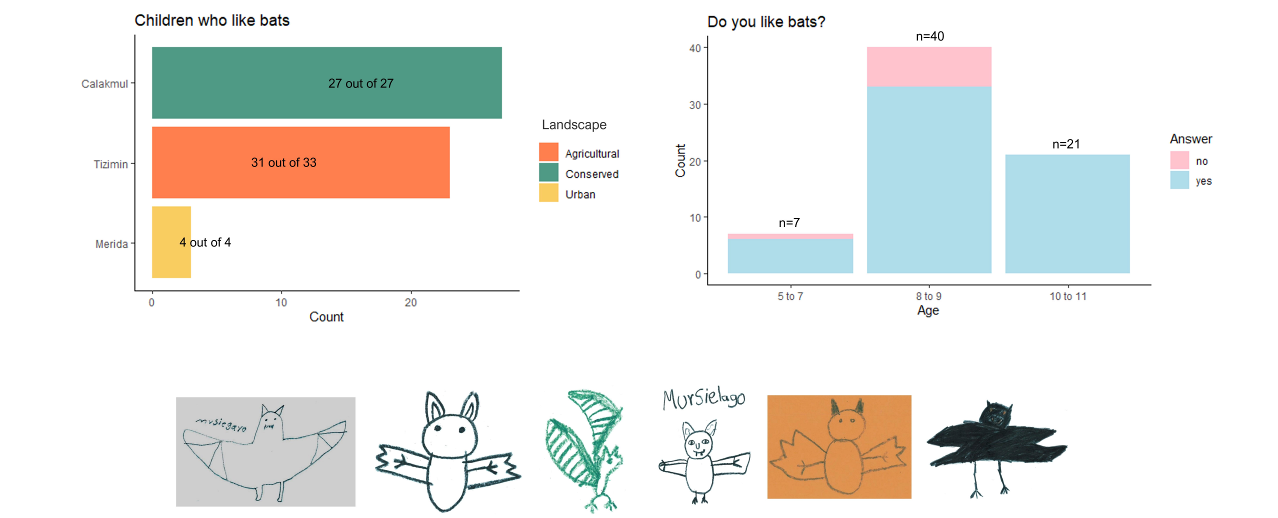

FIGURE 2
Surveys on children's perception toward bats. Results based on a total of 73 questionnaires obtained. Number of children who like bats per landscape (top left); Bat perception provided by scholar children from different ages (top right); Some examples from 94 drawings performed by the children surveyed (bottom).

and hematophagous bats included one species each, observed in agricultural and in the conserved landscapes respectively (Figure 3).

3.3 Microbiome analysis

A total of 108,656,360 paired end raw sequences from fecal microbiome amplifications were obtained. After applying quality-control filters 94,519,756 (86.98%) of paired end sequences and 75,409,547 (69.40%) of non-chimeric denoising sequences remained. In total, we recovered 34,835 ASVs from 77 fecal samples and 12 bat species (Figure 3). The sampling effort was sufficient to assess the microbial diversity present in the fecal samples for most bat species (Supplementary Material S5) suggesting a similar composition according to the beta-diversity analysis (Figure 4; Supplementary Material S6). Alpha-diversity indexes of the fecal-associated microbiome was similar among different bat species at the landscape scale (Supplementary Materials S7, S8), and higher diversity was found in the agricultural landscape (Supplementary Material S8). No statistically different structure of the *A. jamaicensis* fecal microbiome composition was observed between agricultural and urban landscapes, which significantly differ from the conserved area (Supplementary Material S9).

Each bat species analyzed harbors a distinct fecal microbiome which is related to their feeding strategies and landscapes. The predominant bacterial phyla included Pseudomonadota, Bacillota, Actinomycetota, Bacteoridota, Desulfobacterota, Chloroflexota, Planctomycetota, Myxococcota and Verrucomicota (Figure 5). Transient chloroplasts were more abundant in frugivorous bats from the conserved Calakmul landscape (Figure 5).

A few sequences were related to putative pathogenic bacterial families (Supplementary Material S10), which had different relative abundances in bat species (Figure 6). Overall, Enterobacteriaceae, Streptococcaceae, Staphylococcacea and Erwiniaceae formed a large proportion of the fecal microbiome (Figure 6). It is important to note that only the fecal microbiome of *A. jamaicensis* and *G.*

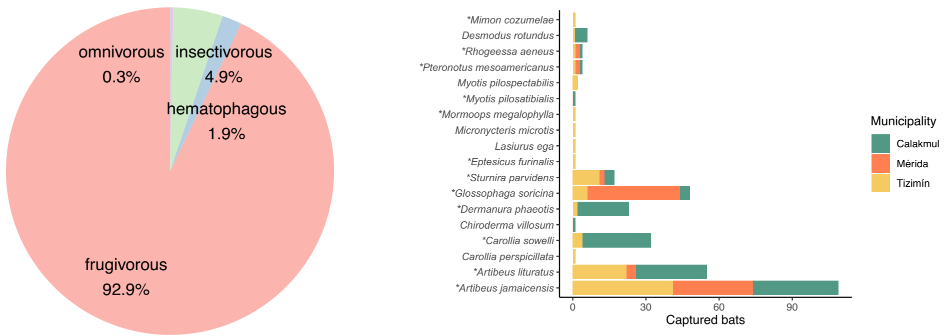

FIGURE 3
Identified bat species and associated feeding strategies. Proportion of observed bats per feeding strategy (left). Number of bats per species among conserved, agricultural and urban landscapes, which respectively correspond to Calakmul, Tizimín and Mérida (right). Bracket colors according to the feeding strategists indicated in the pie chart. Asterisks show bat species assessed in the gut microbiome analysis.

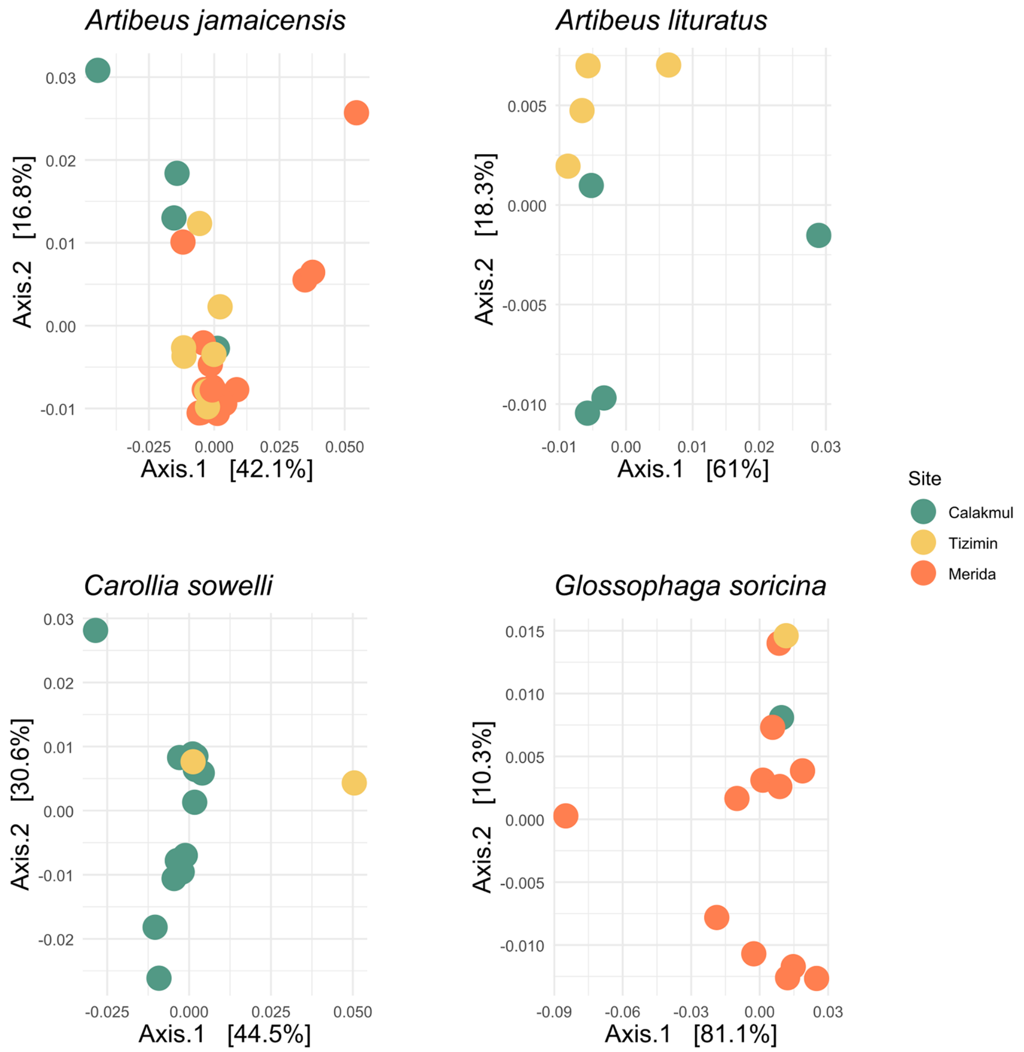

FIGURE 4
Gut microbiome community structure analysis for the most abundant bat species. PCoA ordination method performed with the weighted Unifrac distance matrix from bacterial 16S rRNA gene sequences. Sites correspond to conserved (Calakmul), agricultural (Tizimín) and urban (Mérida) landscapes.

soricina could be assessed across the three landscapes. In *A. jamaicensis*, Enterobacteriaceae and Staphylococcacea were abundant in the conserved landscape (Calakmul), while Streptococcaceae abundance increased in the agricultural landscape (Tizimín), and Erwiniaceae in the urban landscape (Mérida). In *G. soricina*, Enterobacteriaceae clearly dominated the fecal microbiome in all landscapes (Figure 6). Regarding viral pathogens, the focused surveillance of β-CoVs from anal and oral swabs of bats performed following a hemi nested PCR approach, showed no positive results.

4 Discussion

4.1 Local perception towards bats

This study of bats is framed within the basic principles of One Health which recognize the interconnection among humans, animals, and ecosystems (Mackenzie et al., 2014). We aimed to address the coexistence between humans and bats in the Yucatán Peninsula (YP), by combining an educational intervention with ecological and microbiome characterizations. This survey on the biophilic or biophobic actions towards bats, in light of the perception generated after the global pandemic of SARS-CoV-2, provides a basic understanding of local traditions and people's relationship with the natural environment in YP regions (Figure 2). Importantly, because the localities we studied include Mayan populations, our approach and the educational pilot study performed were designed to include aspects of their customs and traditions. Interviewed children revealed that there is an appreciation for bats in local communities, which is not that surprising since they live in contact with wildlife on an everyday basis. Moreover, the cosmovision of the Mayan culture, constructed around a deep relationship with the natural world, respects all living and nonliving things, believing they possess a soul (Lucero, 2018). The bat-god '*Camazotz*' is a Mayan deity which was ancestrally revered and respected (Sieradzki and Mikkola, 2022).

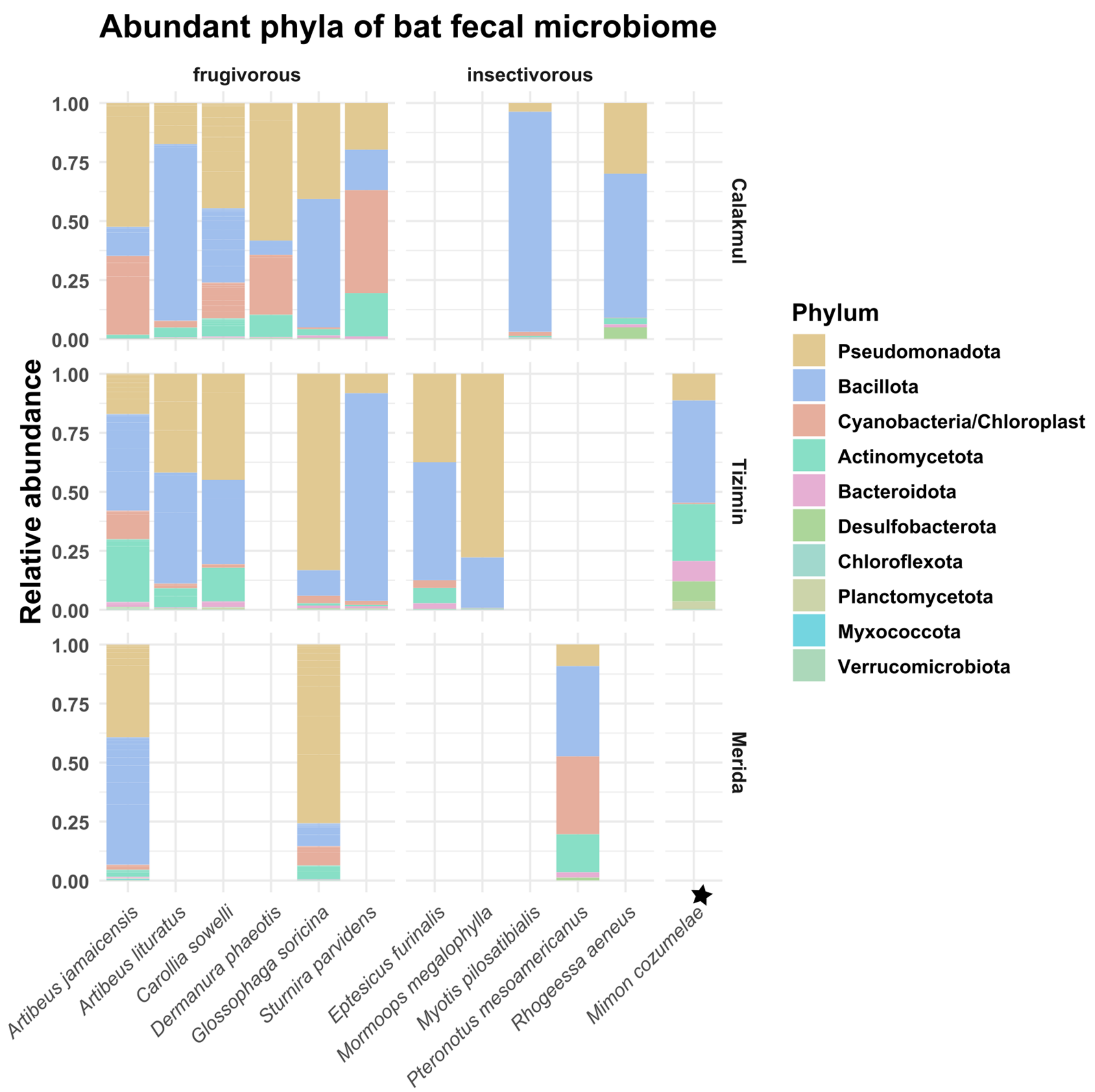

FIGURE 5
Gut microbiome composition. Relative abundances of the top 10 bacterial phyla for the frugivorous, insectivorous and carnivorous bats sampled in the conserved (Calakmul), agricultural (Tizimín) and urban (Mérida) landscapes. Bat species with only one individual is indicated with the symbol ★.

The optimistic reception of the informative talks revealed a latent interest in wildlife among the communities in rural settings, confirming the potential to help bridge the gap between humans and nature.

The outreach activities implemented in primary schools promoted positive feelings towards bats. Collaborative participation with the local communities fosters a sense of coexistence with wildlife and of support for appropriate management of ecosystems. School-aged children effectively permeate knowledge to their younger siblings, parents and to other children through their games. This supports the long-term benefits of educating children, who will grow up to become informed adults. As ecologists we observe that educated children foster greater respect towards nature. Although this is a pilot program for Yucatán, similar educational activities have been replicated in other states of México (RELCOM Latinoamérica, 2024). To develop a long-standing project to promote biophilic responses, we propose that subsequent studies should perform questionnaires before and after educational interventions, broadening the target audience to include a similar number of participants from different ages, socioeconomic contexts and educational levels. Adapting the program for Maya speakers is key. It will also be important to incorporate our locally relevant research findings on bat diversity and microbiomes, making the connection to land use scenarios.

Previous studies performed in the peninsula have addressed various aspects concerning bat fauna, including their composition, morphology and seasonality behavior (Arita, 1997; Rydell et al., 2002; Hernández-Dávila et al., 2012). Others have explored bat responses to habitat fragmentation, the ecological role of frugivorous bats and the importance of habitat management in

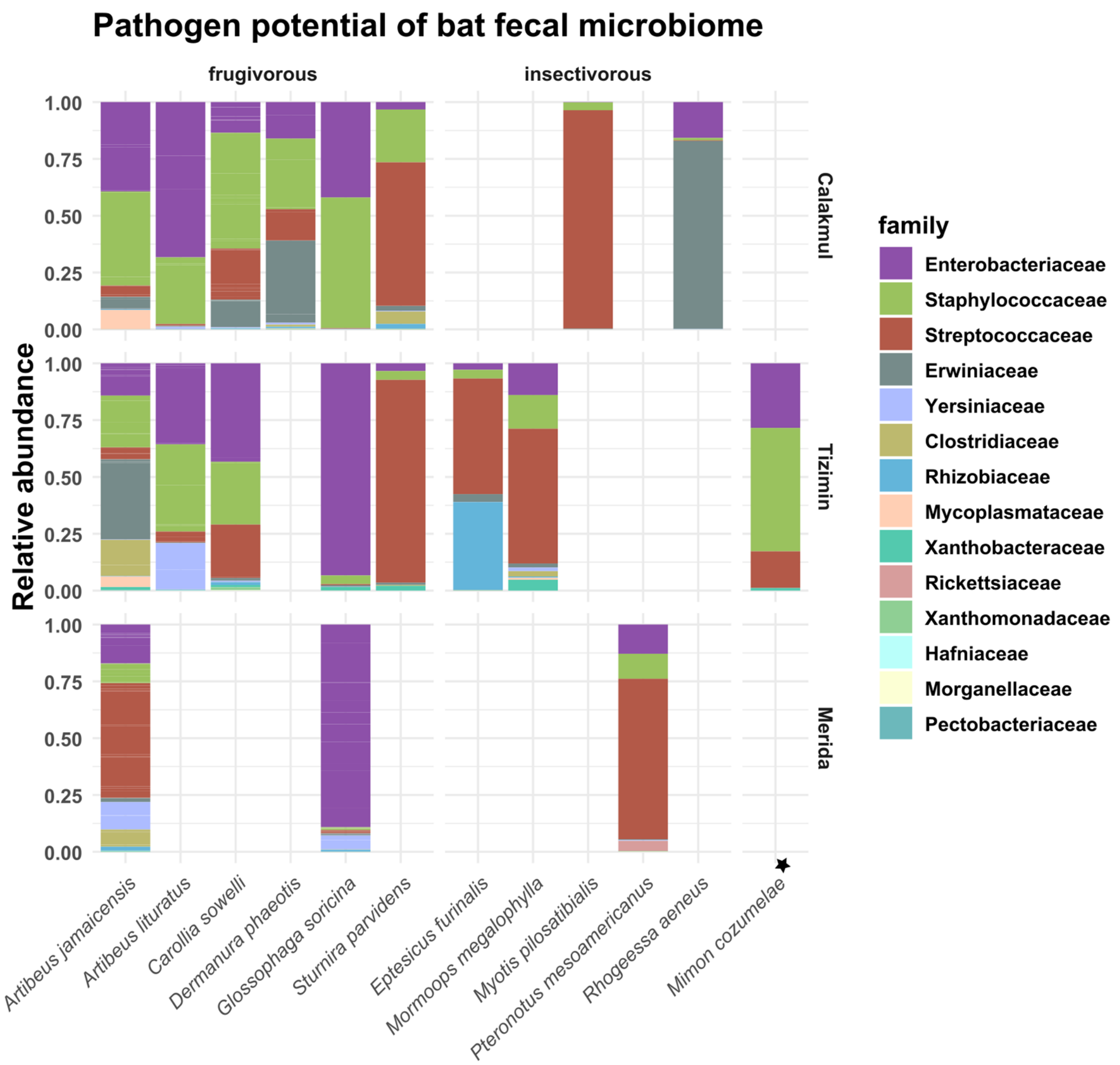

FIGURE 6
Putative pathogenic bacterial families. Relative abundances of bacterial families of epidemiological interest based on 16S rRNA gene sequences compared against specialized pathogen databases. Bat species with only one individual is indicated with the symbol ★.

conserving bat assemblages (Montiel et al., 2006; Vilchis et al., 2007; Medellin et al., 2017; Cafaggi et al., 2024). The presence of zoonotic pathogens in certain bat species has begun to be studied (Machain-Williams et al., 2013; Torres-Castro et al., 2020), including our current research. None of these studies involved outreach to promote biophilic actions towards bats. While educational interventions in the region have focused on preventing specific zoonotic diseases (e.g. Chagas, dengue, rickettsiosis), primary through vector control (Valdez-Tah et al., 2015; Chávez-Arias et al., 2017; Dzul-Rosado et al., 2023), there is a lack of initiatives promoting a positive relationship between local communities and bats and other natural insect predators. Recognizing the interconnection between nature and society, conservation biology, and applied ecology emphasize that effective management of nature is both an outcome and a driver for social, economic and ecological changes (Cumming and Allen, 2017). Driven by this understanding, our research team is committed to generating scientific knowledge, while developing and implementing more effective strategies that foster stronger connections between nature and local communities.

4.2 Ecological insights of bats and their gut microbiome supporting biophilia

Findings suggest that land use differences in the YP are a factor affecting bat diversity and their microbiome composition. Notably, bats are recognized as indicator or sentinel species (Jones et al., 2009; Wolf et al., 2022). During the present study, a higher diversity of bat species was registered in agricultural dominated (Tizimín) and conserved (Calakmul) (Figure 3) than in urban landscapes. The interconnection of natural habitats and the adjoining managed lands, where silvicultural activities are performed, are likely serving as biological corridors, supporting bat dispersal and providing habitat and food availability. This suggests that these corridors contribute to biodiversity conservation allowing connectivity between populations, communities and ecological processes in fragmented landscapes (Laurance, 2004 Bolívar-Cimé et al., 2013). The Calakmul Biosphere Reserve is part of the Mesoamerican Biological Corridor, a region of great biodiversity (Vester et al., 2007). It harbors the largest region of continuous rainforest in the Americas, second only to the Amazon. This reserve still sustains populations of large mammals, including Baird's Tapir (*Tapirus bairdii*),jaguar (*Panthera onca*), and the largest diversity of bats reported (Vester et al., 2007) (Figure 3). Further, across the study sites (Figure 3), we found a higher abundance of opportunistic fruit eating bats, such as *A. jamaicensis* (Montiel et al., 2006; de Souza and Vizentin-Bugoni, 2020), and a scarcity of insectivores that are more environmentally sensitive to landscape changes (Threlfall et al., 2011). Particularly for the Calakmul reserve, these results might be explained by potential habitat loss due to the increasing establishment, expansion and intensification of agricultural activities (Vester et al., 2007; Špirić et al., 2022). Unfortunately, this process is doomed to continue because Calakmul is further threatened by fragmentation triggered by a controversial train that will run through the heart of this nature reserve (Ortega and Jaber, 2022).

The high abundance of frugivorous bats, especially of *A. jamaicensis* in urban areas, demonstrates their great adaptability to fairly hostile and resource-limited conditions (Moretto et al., 2023). This adaptability likely relies on diversifying their food sources, which enables them to displace the more selective or dietary specialized species that are not able to persist in such fragmented ecosystems (Meyer et al., 2008; Montiel et al., 2011). Bat species that tolerate urban and suburban habitats in the YP are vital for the sustainability of forests as seed dispersers, contributing to forest regeneration (Hougner et al., 2006; MacSwiney et al., 2017). Furthermore, bat species that are better adapted to human modified landscapes will continue to interact with urban human populations, which are expected to be poorly connected to, and knowledgeable of, natural landscapes (Moretto et al., 2023). Experiences that combine education and immersion in natural landscapes have a positive influence on human behavior (Dzul-Rosado et al., 2023). Thus, it is fundamental to continue with the design and implementation of educational strategies in the region that promote biophilic responses towards bats, while informing the different actors of the key environmental benefits they provide.

Microbiome assessments are essential tools to monitor microbes of zoonotic importance, and this information significantly impacts the perception towards bats and the way people indirectly interact with them in the YP. As part of this ongoing research, we aim to incorporate the microbiome knowledge here generated in future outreach activities to continue promoting bat conservation and public health. The low abundance of insectivorous bats observed in this survey suggests a potential loss of biological insect control. Molecular identification of prey remains in insectivorous bat feces has revealed the consumption of insects, including mosquitoes that can transmit diseases of medical importance (Burgar et al., 2021). Given the prevalence of mosquito-borne diseases in the YP, such as dengue, Zika and West Nile Virus (Sánchez-Soto et al., 2024), insectivorous bats can perform a role in controlling populations of these disease-vector insects.

Importantly, food resources influence the host microbiome. Hence, microbiome data offers valuable insights into the potential ecological consequences of land-use changes on bat populations. Our results show differences between the gut microbiome of the frugivorous *A. jamaicencis* from conserved areas and that from suburban and agricultural settings (Supplementary Material S9), likely as a result of differences in food resource quality, abundance and diversity, and/or by exposure to novel bacteria (Carrillo-Araujo et al., 2015; Ingala et al., 2021). This study can establish a reference of the diversity and composition of the gut microbiome in contrasting landscapes of the YP. It can serve as a basis for future studies to evaluate the effects of habitat modification on bat health and fitness, and the relation between habitat modification and potential pathogens spillover and transmission (Ingala et al., 2018). In this regard, an important research venue would be to survey bacteria of clinical interest in bat microbiomes (Cláudio et al., 2018), to perform zoonotic risk analysis to address effective control measures in priority areas with presence of specific pathogens.

Nonetheless, it is important to emphasize that the presence of opportunistic potential pathogens in the gut microbiome (Figure 6) does not indicate that bats in the YP are reservoir hosts for the transmission of bacterial zoonotic diseases (Wolkers-Rooijackers et al., 2018). Results show that the individual bats analyzed did not host β-CoV. In a recent study, Colunga-Salas and Hernández-Canchola (2020) analyzed sequences for the ORF1ab polyprotein of CoVs detected in 11 bat species distributed in México and confirmed that SARS-CoV-2 was not present. Although these bats did not present a zoonotic disease threat, there is evidence of certain viruses associated with *A. jamaicensis*, including influenza, dengue, Zika, West Nile and rabies, which could contribute to potential disease spread (Cabrera-Romo et al., 2016; Almeida-Campos et al., 2019; Torres-Castro et al., 2021). Yet, we underline the need for wildlife microbiome surveillance that aids in the assessment of public health risks in the region (Sánchez-Soto et al., 2024). Considering that bats are key species that indicate the health of ecosystems, their gut microbiome will also be representative at the landscape level and could be monitored with relative ease.

Far from generating a negative perception towards bats, addressing public concerns about these flying mammals is essential for bat conservation, since negative attitudes frequently stems from misinformation, fear, and a lack of awareness about the key environmental benefits they provide (Lu et al., 2021; Ramirez-Francel et al., 2022). Current dominant socioeconomic models have ignored the relation between human population growth, habitat modification, and ecosystem health. Our findings support that land use has an impact on bats' diversity and their microbiome, whereby the diversity of bats decreases in the most urbanized sites and their gut microbiome tends to be more similar in modified landscapes. Bat diversity in the YP was dominated by frugivorous species, suggesting loss of other ecosystem services, such as insect control by bats that can consume large quantities of insects, including those that transmit diseases. The lower the insect predators, the higher the potential of some zoonotic diseases and spillover, such as dengue, Zika and others. Pollinating bats are also essential in the ecosystems; changes in land use and fragmentation affect this bat guild. Clearly, studies that promote biophilia responses in the YP are fundamental; while surveying bat populations and their microbiome dynamics offer an indirect means to understand ecosystem health. A biophilic approach promotes healthy bat populations in hand with sustainable development, while it is in healthy ecosystems that zoonotic diseases will be controlled.

Data availability statement

The original contributions presented in the study are publicly available. This data can be found here: NCBI BioProject, accession PRJNA1153560.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants legal guardian/next of kin.

Author contributions

MS-S: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing, Validation. OG: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. RM-J: Data curation, Formal analysis, Methodology, Visualization, Writing – review & editing. AY-M: Methodology, Writing – review & editing. AL-L: Methodology, Writing – review & editing. GB-M: Data curation, Methodology, Writing – review & editing. DZ: Formal analysis, Methodology, Writing – original draft. SR-G: Writing – review & editing, Methodology. EH-V: Writing – review & editing, Methodology. AM-S: Methodology, Writing – review & editing, Funding acquisition, Project administration. JD: Funding acquisition, Resources, Project administration, Writing – review & editing. GS: Conceptualization, Funding acquisition, Project administration, Resources, Writing – review & editing. EV-D: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Resources, Visualization, Writing – review & editing, Project administration, Supervision. LF: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author (LIF) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2024.1488378/full#supplementary-material

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Protecting urban wildlife fauna, fighting zoonoses, and preventing biophobia in Brazil

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Biophobia has increased worldwide, particularly in high-income countries, leading to the loss of natural interactions and fewer health and wellbeing benefits for humans and animals. Wildlife avoidance in Brazilian urban settings has been mostly directed to synanthropic species (so-called "harmful fauna") due to the risk of zoonosis and mostly involves bats, capybaras, opossums, and monkeys. Additionally, feral cats and stray dogs prey on vulnerable wildlife fauna, decreasing biodiversity. Wildlife protection groups have contributed to this biophobia by demanding the capture and relocation of local wildlife to distant states and federal parks. Nonetheless, some Brazilian state capitals peacefully coexist with steady or growing urban wildlife. Accordingly, this study aimed to present initiatives for wildlife protection, zoonosis surveillance, and biophobia prevention in Curitiba, the eighth-largest Brazilian city in the world and considered among the most sustainable cities in Latin America. Instead of sole sustainability, the One Health approach has been applied to address animal, human, and environmental health as part of city priorities, including free-of-charge veterinary services, basic school education, and a newly established public veterinary hospital. Animal Protection Services, City Secretary of Environment, has promoted substantial improvements in pet guardianship and urban wildlife fauna protection, with an updated city wildlife inventory, attendance, and release of native fauna into city parks. Meanwhile, the Zoonoses Surveillance Unit (ZSU), City Secretary of Public Health, has worked daily to prevent zoonoses and other public health issues, particularly bat rabies, with minimal impact on city wildlife. Children's outreach and educational handbooks, inserted into teaching content in basic schools, are used to prevent biophobia in future generations. In summary, Curitiba may serve as a model for the One Health approach (in addition to sustainability) for the concomitant improvement of animal health and wildlife protection in major cities in Brazil and worldwide.

KEYWORDS
sustainability, One Health, biophilia, rabies, bats, rats

1 Introduction

Biophobia (*Bio*, life + *phobus*, fear), defined as fear, disgust, aversion, or other negative feelings in response to certain natural stimuli, prevents natural interactions, including with unharmful wildlife organisms, reducing emotional connection toward nature, decreasing pro-environmental behavior and actions, and leading to an increasing cycle of detachment and alienation from nature (Soga and Gaston, 2016; Soga et al., 2023). This phenomenon has been increasingly observed in the highly populated urban areas of contemporary societies in high-income countries, where excessive biophobia has been suggested to be a common phenomenon (Soga et al., 2023). The loss of contact with nature has also been associated with the extinction of experience (Miller, 2005; Soga and Gaston, 2016), which in turn has been linked to the decrease of environmental concern by urban residents, currently accounting for nearly half of the worldwide population (Miller, 2005). In addition, teaching fear and aversion during childhood, particularly in avoidance of animal-to-human diseases, may induce future biophobia (Zhang et al., 2014; Soga and Evans, 2024). Moreover, elevated biophobia may negatively affect biodiversity conservation, including a reduced willingness to coexist with wildlife and protection policies, along with undervaluation of their benefits (Soga et al., 2023). Interestingly, biophobia in urban settings may be justified as animal conservation translocation, with the capture and relocation of native animal species to wildlife reservations, which has questionably increased populations and genetic variability, particularly in endangered species (Conservation translocations: a review of common difficulties and promising directions, 2020). It may also have a dangerous impact on lower and more fragile urban biodiversity, reaching an abiotic point of no return. Increasing biophobia may create feedback cycles, which may magnify individual or collective fear or disgust perceptions towards nature, with reported examples of such vicious loops (Soga and Evans, 2024). Assessment of Chinese school children in urban settings has suggested that nature contact may increase their indirect motivation to support animal conservation by developing positive attitudes toward wildlife (Zhang et al., 2014). Similarly, Japanese children presenting negative attitudes (biophobia) towards invertebrates have shown a decrease in direct nature experiences, which may have triggered increased biophobia (Soga et al., 2020). In such a scenario, efforts to reestablish human connections with the natural environment through meaningful interaction should be strongly considered and applied (Bennett and Reyers, 2024).

In contrast, biophilia (*Bio*, life + *philia*, affection) has been defined as "the urge to affiliate with other forms of life," as an innate desire to enjoy contact with living nature (Barbiero and Berto, 2021), historically counterpoising biophobia and proposing a more balanced approach, particularly in urban settings, with incorporation into architecture instead of nature avoidance. Although the human evolutionary past has been closely associated with nature, modern societies, particularly teenagers and children, have increasingly lacked direct and frequent contact with wildlife, which can negatively affect physical and mental health (Oswald et al., 2020). A statistically significant and positive relationship was found between nature interaction and mental health, particularly focused on attention deficit and hyperactivity disorders, according to a systematic review (Tillmann et al., 2018). In China, young adults living in urban areas with direct or indirect natural contact have improved strategies of feeling regulation by cognitive reassessment and control (Gu et al., 2023). Thus, a positive response to nature, including predilection and recognized repair, may be learned and dependent on positive emotional associations (Barbiero and Berto, 2021). In addition, the presence of neighborhood natural areas may improve the general health of adults through physical activity, social contact, and subjective well-being, based on an analytic study in 18 countries (Elliott et al., 2023). Finally, the health and wellbeing benefits of biodiversity in urban areas may surpass the negative effects such as viruses and pollen and may be considered nature-based solutions to address public health concerns, according to a review study (Marselle et al., 2021). The replacement of natural grass, plants, bushes, and trees with sand, gravel, asphalt, artificial grass, and concrete, both outside and inside households, has been justified by cleaner (no mud or leaves) pathways, easier washable areas (such as backyards for pets and vegetables), and fewer synanthropic insects such as ants and termites. Although modern, practical, and useful, a lack of outdoor (and indoor) greenness may deteriorate mental health, as natural exposure has been associated with improvements in physical health such as reduced blood pressure, heart rate, inflammation, stress, anxiety, and depression (Paniccià et al., 2024). In São Paulo, the largest Brazilian city, the fear of branches and trees falling onto people and vehicles after heavy rainfall and of storms damaging walls and houses has condemned large tree canopies and their centuries-old trunks, replacing avenues with cemented sidewalks disturbed only by posts, traffic signs, and garbage cans. The fear of flooding has led to the canalization of entire rivers, suffocating riverside fauna and flora, and manmade underground "pools" made underneath parking lots of São Paulo being built to accumulate the fast-moving rainfall water that floods streets and sidewalks, which can no longer absorb water (FAPESP and AGÊNCIA FAPESP, 2021; Millington, 2021; BBC, 2024). Such fear and avoidance of nature, associated with the apparent lower cost of cleaning and maintenance, have replaced entire lawns of sidewalks, squares, parks, and even backyards with cement and concrete; such areas are commonly isolated by fences, iron grilles, and brick walls. Surrounded by cement and asphalt, trees have been suffocated with little space and water, falling by the dozen during heavy rainfall and thunderstorms in 2024, causing several long-lasting blackouts affecting over half a million people (Jornal da USP, 2024). Curitiba, the eighth largest Brazilian city and considered the most sustainable nationwide, has dealt with flooding by doing the exact opposite— avoiding concrete and asphalt, increasing the soil drainage capacity throughout the city, and using low-level parks as natural pools for rapidly moving flooding (IBGE, n.d.; Curitiba, 2024a).

Pesticides, insecticides, and rodenticides have been ostensibly used in urban areas to control weeds, ants, mosquitoes, termites, and rats, and are often applied by the city hall itself, without any study on their long-term environmental impact. Large urban centers may turn into "concrete jungles" dominated by concrete and asphalt, with glass walls buildings and concrete cell phone towers mimicking trees which cause fatal collisions with birds every year. Not surprisingly, the number of birds killed every year in the USA by glass collision has been estimated at 365–988 million, surpassed in anthropogenic impact to avian life only by birds killed by free-ranging domestic cats, estimated between 1.3–4.0 billion deaths per year (Schneider et al., 2018). In such a scenario, frogs, dragonflies, fireflies, endangered butterflies, and other native wildlife species gradually became memories, part of grandparents' stories, and urban legends of major cities, reducing natural biomes and ecosystems and impairing the capacity of resilience and self-renovation of such environments.

In addition, the growth of Brazilian road infrastructure towards the countryside to transport agricultural goods and travelers is another important factor in biodiversity losses, mostly due to roadkill and biome fragmentation, with roads splitting into natural areas with no wildlife protection or safe crossing (Navas-Suárez et al., 2022). With no practical answer to date in Brazil, wildlife safety on roads has become crucial for conservation, requiring passages by bridges and tunnels, a nationwide notification system for fauna roadkill, and mapping of critical (fatal) road points for signage and other preventive measures (Navas-Suárez et al., 2022). Accordingly, the present study aimed to provide an overview of biophilia/biophobia in Brazil and public practices to prevent zoonoses while protecting Brazilian wildlife and, concretely, to describe the biophilic actions performed in the city of Curitiba.

2 Methods

The present study provides an overview of biophilia/biophobia in Brazil and the current initiatives of Curitiba, considered one of the most sustainable cities in Latin America.

3 Human-wildlife interactions in ancient Brazil

Although historically threatening human survival and evolution through predation and diseases (direct and vector-borne), wildlife fauna have also provided essential animal-based proteins for human survival (Pettan-Brewer et al., 2021). Perceptions of human and animal health and their interconnectedness have long appeared in the traditional understanding of indigenous peoples in Latin America. Preceding humans by millions of years, animals have profoundly impacted what became Latin America, while the appearance of humans has similarly affected the health and life of native fauna, with a long history of predation starting with the potential extinction of several Latin American megafauna species by the Paleo-Indians (Zhang et al., 2014). Although the domestication of livestock by wildlife has increased protein demand worldwide, not a single Brazilian native animal species has been domesticated by Brazilian indigenous peoples (Camphora, 2017). At the time, domesticated animals in the New World included only two large birds, turkeys in North America and Muscovy ducks in Central America; four Andean species, two camelids, llama, and alpaca; and two medium-sized rodents, guinea pigs and chinchilla species (Stahl, 2008). Although one report suggested that the few pre-Columbian domesticated species were the result of geographical peculiarities associated with limited domestication candidates after the massive extinctions of the Pleistocene (Diamond, 2005), several native Brazilian species were docile and later domesticated and are currently used for commercial purposes, including several caimans, peccaries, water turtles, tortoises, and bird species (Trajano and Carneiro, 2019). As several Brazilian indigenous peoples may have lived 20–30,000 years in the pre-Columbian era, the lack of animal domestication may have been a result of human decisions, in an unprecedented One Health approach to their own lives, over thousands of years (Supplementary Figure 1) (Pettan-Brewer et al., 2024).

Indigenous populations were dynamic and hostile, with their survival relying on warfare, diverse weapons, soldier skills, and food tactics. Even so, health and wellbeing are intrinsically connected to sophisticated natural knowledge acquired over centuries concerning the balanced use of local ecosystems. Despite reservoirs and sources of soil, water, food, and vector-borne diseases, wildlife (and plants with environmental health impacts) were also used as treatments, amulets, and part of religious rituals at the time (Pettan-Brewer et al., 2021). Thus, the non-submissive balance of human, animal, and environmental health in ancient Brazil may be considered one of the most enduring examples of One Health in history, long before the term was coined (Sibim et al., 2024).

Following the European invasion of the late 15th and early 16th centuries, the Columbian exchange brought exotic livestock species from the Old World, including cattle, sheep, dogs, and horses, leading to another extinction wave of native American species, mostly by turning nature into pastures, bringing livestock diseases to wildlife, and using firearms, horses, and dogs for large-scale wildlife hunting, partially for synergetic purposes (Stahl, 2008). Brazilian indigenous peoples, once sovereign of their vast and unlimited lands, are currently considered highly vulnerable populations, restrained to federal reservations, mostly located within environmentally protected areas, and suffering from post-Columbian zoonotic diseases aggravated by the overlap of humans, companions, livestock, and wildlife (Camphora, 2017). In such a scenario, for better or worse, animals have influenced and are being influenced by indigenous history in an adaptive and interdependent human-animal relationship in Brazil and Latin America, which should be analyzed, understood, and applied by current and future generations (Pettan-Brewer et al., 2024).

As flagged in 2019 by Ailton Krenak, renowned indigenous leader, environmental advocate, philosopher, poet, and the first-ever indigenous person elected to the Brazilian Academy of Letters, "no humanity exists apart from Nature", meaning that wildlife should be respected as one's own family and heritage instead of an available source of resources (Krenak, 2024).

4 Development of biophobia in major Brazilian cities

In the most highly populated Brazilian cities, beneath the impermeable cover of concrete and asphalt, the original course of rivers crossing urban areas is reborn during each rainfall storm, causing increasingly larger and more frequent floods. Until a few decades ago, washerwomen could be seen in the Anhagabaú River Valley, downtown São Paulo, the biggest Brazilian city that currently constantly suffers from flooding and falling trees, damaging electric posts and cables, leading to days of power outages (Millington, 2021). A similar fate occurred to the native fauna of the city, as native birds and bats in São Paulo have been gradually replaced by invasive and exotic birds, much less targeted and more adapted to food leftovers and trash produced daily by metropolitan life (Fontoura et al., 2013). Likewise, neighborhoods of the second largest city in Brazil, Rio de Janeiro, have suffered from the proliferation of synanthropic fauna, including rats, pigeons, and cockroaches, favored by outdoor trash and a warming climate (Fontoura et al., 2013). In this scenario, One Health has been compromised in three ways—environmental health with trash and degraded nature, animal health through pest control and zoonoses, and human health with exposed people living in such areas.

The term synanthropic (*sin*, with + *anthropo*, human being) fauna has been used in Brazil to designate "urban pests" as animal species capable of potentially harming human health through a biocidal approach to public, animal, and environmental health, mostly conducted by zoonosis surveillance units distributed nationwide (Ministério da Saúde, 2024). However, the term synanthropic fauna was originally used to designate animal groups living close to human beings, particularly in cities, mostly because of the peridomestic supply for their survival needs, including water, food, shelter, and mating. Synanthropic fauna currently comprises both exotic invasive animal species (rats, pigeons, cockroaches, and flies) and native fauna, such as snakes, bats, opossums, spiders, scorpions, mosquitoes, ants, fleas, bees, and wasps, which have been poisoned, trapped, controlled, and relocated by city animal services in major Brazilian cities, sometimes as part of city laws.

Although synanthropic fauna has been called "harmful fauna," such native species have reportedly assisted in pollination, plant health (bats and bees), and predation of cockroaches, mosquitoes, and flies (bats, spiders, and scorpions). Nonetheless, complaints have been made by residents of the neighborhood of Penha, Rio de Janeiro, due to bats invading at night searching for almond trees, desperately demanding removal since "bats have invaded apartments, defecated on trees, sidewalks, and households, terrorized people and represented a real risk of fatal diseases (rabies)" (de Lima et al., 2023). This clearly shows avoidance and unawareness of the benefits of bats in a city that has suffered from Dengue fever mosquitos over decades. In addition, an increase in cat rabies has been reported due to cat-bat interactions and predation in urban areas, with cats being ten-fold more likely than dogs to be infected with rabies (de Lima et al., 2023). Although Curitiba created a handbook to better explain bat rabies risk and ecosystem importance, such educational programs should be provided nationwide (Supplementary Figure 2) (Rede de Protecao Animal, n.d.).

Due to the lack of natural predators, imbalances in the natural food chain have made capybara a problem, as overpopulation has been observed in lakes, parks, and condominiums in large Brazilian cities, such as São Paulo and Belo Horizonte. Because capybaras may host ticks responsible for Brazilian spotted fever, fear has driven residents to request euthanasia and relocation instead of tick management and proper sanitation. In addition, exotic fauna, such as feral cats, stray dogs, and invasive opossums and marmosets, may prey on the high and vulnerable fauna biodiversity living in urban settings, endangering hundreds of native species, including birds, rodents, and other small vertebrates and insects. On the other hand, regular citizens, animal protectors, and non-governmental animal protection organizations have pushed back against legislators regarding animal cruelty, mostly protecting domestic pets (mostly dogs and cats) and livestock (chariot-horses) species. Although justified for animal health and welfare, such urban restrictions have also removed animals from daily contact with residents, contributing to the "abiotic" process in large Brazilian cities. Another fear, expressed as wildlife protection, has made city animal services capture and relocate parrots, parakeets, opossums, snakes, monkeys, and other animals, which are released into state and federal reserves, forests, and parks, often in areas far away from the city squares and parks where they were found. In such a process, wildlife protection groups have mimicked biophobia, as native species have been forced to emigrate based on "take it from here and release it somewhere else better for it."

During the yellow fever outbreak in Brazil in 2018–2019, the impact on biodiversity loss was due not only to direct viral action in native non-human primates but also in some threatened species such as howler monkeys (Hance and Mongabay Environmental News, 2009; Romero, 2017). Native non-human primates were systematically hunted and killed by the general population due to avoidance and fear of yellow fever transmission (de Oliveira Figueiredo et al., 2020).

5 Lack of animal health and wildlife protection in the worldwide agenda

Although the 17 Sustainable Development Goals (SDGs) established by the United Nations (UN) are a global challenge that includes, education, environmental protection, peace, prosperity, and ending poverty for world citizens by 2030, no SDG has been specifically proposed for animal health and welfare, with animals mentioned only once in the full document (United Nations, n.d.; Negrini et al., 2024). In addition, despite being used several times in the SDGs, sustainability has no animal health in its measurement, meaning that any given city, state, or country may be deemed sustainable without any commitment to domestic animals, livestock, or wildlife (de Moura et al., 2022a). In such a scenario, Curitiba has won several awards as the most sustainable city in Brazil and Latin America and a few times worldwide, without presenting any commitment to animal health and welfare (Stavri and Greenzine, 2021; Gortázar and El País English, 2023). Biophilia, therefore, remains a challenge at the city, state, country, and global levels on the long journey to sustainability.

Besides Brazil being a UN signatory country for SDG challenges, the country also incorporated One Health into its agenda, establishing the first federal instance of animal rights in its history in 2023, the National Department of Animal Protection and Rights (DAPR), in the Ministry of Environment and Climate Change (Ministério do Meio, n.d.). Despite focusing on pet population management, mass neutering/spaying programs, and stopping animal cruelty, the DAPR aims to establish a Federal Animal Code and other nationwide regulations, including welfare meat production, meat substitutes, and the reinforcement of wildlife fauna protection in urban areas (Ministério do Meio, n.d.; Negrini et al., 2024). One important step was recently accomplished with the National Pet Animal Registry, using identification cards based on Federal Law 15,046 of December 18th, 2024 (Supplementary Figure 3) (Jornal Nacional, 2024).

Although fighting biophobia may be contemplated through wildlife protection and reinforcement, no specific countrywide program has been implemented to date. The Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), responsible for wildlife fauna, municipalized the rescue, apprehension, registration, and microchipping, with immediate (if possible) or after-treatment (when necessary) release within city green areas and parks, in an unbureaucratic and unprecedented manner. The majority of the 26 Brazilian state capitals and the Federal District (Brasilia) peacefully coexist with steady or growing urban wildlife in each of the six Brazilian biomes, including toucans, parrots, agoutis, monkeys, sloths, capybaras, armadillos, and anteaters, without excessive fear or avoidance. Foster and definitive adoption programs for stray dogs and cats have become increasingly common in major Brazilian cities, gaining persistent community support as part of the multispecies family. Accordingly, this study aimed to present official data and initiatives for wildlife protection, zoonosis surveillance, and awareness of biophobia in Curitiba.

6 Curitiba as a model of a sustainable city

Curitiba (25°25′40″ S and 49°16′23″ W), the capital of Parana State, was ranked as the 8th biggest city with approximately 1.87 million inhabitants, 10th in human development index (HDI) with 0.823 (very high), and 6th in gross domestic product (GDP), out of 5,570 municipalities in Brazil at the time of the survey. Curitiba is situated in a subtropical highland climate region, classified as an urban area only, and is considered one of the most planned and sustainable cities in Latin America, with an average of 64.5 m^2 of green area per inhabitant (Gadda et al., 2021). According to recent studies, despite the challenges of human population growth, Curitiba ranks fifth nationwide in afforestation of public ways among major cities, with approximately 20% of its territory covered by forested areas distributed in 49 city parks and other green areas (Gadda et al., 2021).

An approach to a study on Curitiba from an international perspective may be based on the number of studies conducted with a focus on zoonoses, One Health, and biophilia (AND biophobia), assessed by a systematic literature review in the Web of Science (WoS) database, using the following driver—(zoono* OR "one health" OR biophilia) AND (city OR municip* OR town OR urb*) AND (Curitiba). In this driver, zoono* captured the term "zoonosis" and its derivatives, while municip* and urb* target the terms "municipality" and "urban," respectively, including their derivatives. The terms city, municipal *, town, and urban * are essential to distinguish studies specifically conducted in the city of Curitiba from those merely associated with the city, such as studies conducted by researchers affiliated with the Federal University of Paraná headquartered in Curitiba. The results were exported in text format and bibliometrically analyzed using the free software VOS viewer version 1.6.20. The main zoonosis studies in the municipality and their interrelations with the animal population were identified using a bibliometric network based on primary keywords from the manuscripts in the surveyed database. For this analysis, only keywords provided by the authors that appeared in at least three different documents were considered and included. A total of 146 publications addressing zoonoses, One Health, and one on biophilia, conducted in the municipality of Curitiba, were assessed. The first two studies were published in 2007, and 23 publications were published by 2024. The Boolean operator AND was included in the syntax, meaning that the sampling included only documents containing all the specified keywords, thereby restricting the scope of the search, i.e., including studies that mentioned "Curitiba" and excluding those that did not contain this term. Thus, the results addressed this issue. In December 2024, when the term "Curitiba" was included in the search string, a total of 146 documents were obtained in WoS, whereas, for example, when the term was replaced with "Warsaw," the number of manuscripts was reduced to 58. When performing the search in WoS, on 16 March 2025, using the driver (zoono* OR "one health" OR biophilia OR biophobia) AND (city OR municip* OR town OR urb*), a total of 12,523 results were obtained. This indicated that the term "Curitiba" significantly restricted the results, directing them toward the specific object of the study herein. Curitiba demonstrated a high volume of publications compared with other cities worldwide with similar population sizes (Table 1).

The proposal of the present study was a comparison between cities, and thus a comparative approach rather than an absolute survey. As the sampling was robust, the absolute value (while respecting the sampling restrictions) may not be relevant; rather, the relative values among the number of publications across cities should be considered of comparative importance. For this reason, WoS, the dominant database (Zhu and Liu, 2020), may be the appropriate approach for the purpose herein. In addition, the driver has been applied to the Scopus database for each city covered in the present study (Table 2), following a comparative analysis of WoS and Scopus (Mongeon and Paul-Hus, 2016). Regardless, most of the results obtained herein from the Scopus database were also present in the WoS database.

TABLE 1 The number of publications on zoonoses, One Health, and biophilia in various cities worldwide with similar populations, highlighting Curitiba, PR, Brazil.

City	Country	Population (mi)	Manuscripts
Barranquilla	Colombia	2.0	30
Budapest	Hungary	1.7	74
Cordoba	Argentina	1.5	91
Curitiba	Brazil	1.8	146
Guadalajara	Mexico	1.6	13
Hamburg	Germany	1.8	87
Philadelphia	USA	1.6	109
Sapporo	Japan	2.0	199
Vienna	Austria	1.7	118
Warsaw	Poland	1.7	58

TABLE 2 The number of publications on zoonoses, One Health, and biophilia in various cities worldwide with similar populations, obtained from WoS and Scopus, with a focus on Curitiba, PR, Brazil.

City	Country	WoS (Dec 2024)	Scopus (Mar 2025)
Barranquilla	Colombia	30	7
Budapest	Hungary	74	6
Cordoba	Argentina	91	13
Curitiba	Brazil	146	24
Guadalajara	Mexico	13	0
Hamburg	Germany	87	4
Philadelphia	USA	109	1
Sapporo	Japan	199	7
Vienna	Austria	118	11
Warsaw	Poland	58	12

Despite a previous practical guide has been provided to question formation, systematic searching and study screening for literature reviews in ecology and evolution (Foo et al., 2021), the results herein may be considered robust as 1) the data explored were from the most relevant database for the purpose of the present study and 2) the results discussed were comparative rather than absolute among the cities.

The primary zoonoses studied were toxoplasmosis and leptospirosis (each with 13 occurrences of related terms), followed by leishmaniasis (nine occurrences) and Brazilian spotted fever (six occurrences) (Figure 1). Other diseases highlighted among the main keywords included hepatic fascioliasis, rabies, toxocariasis, and Q fever (each with four related terms). In Curitiba, the most frequently studied animals were dogs (18 cases), cats (seven cases), and cattle (three cases). Leptospirosis, toxoplasmosis, and rabies were linked to dogs, rabies and toxoplasmosis to cats, and hepatic fascioliasis to cattle.

7 Curitiba Animal Protection Services

Curitiba has been historically known for advanced animal protection laws, including the banning of animal circuses, rodeos, or other animal shows since 2007 (City law 12,467 of October 25th, 2007) (Curitiba PR, 2007), typifying animal cruelty since 2011 (City law 13,908 of December 19th, 2011) (Curitiba, 2011), banning chariot horses since 2015 (City law 14,741 of October 27th, 2015) (Curitiba, 2015), animal protection as city policy since 2021 (City law 15,852 of July 1st, 2021) (Curitiba, 2021), and updated fines and penalties against animal cruelty established in 2022 (City law 16,038/2022) (Curitiba, 2022c). In 2023, a pet population survey conducted by a consulting company resulted in a statistical estimate of 584,661 dogs and 185,379 cats in the city (Curitiba, 2024b).

The Department of Animal Protection, a part of the City Secretary of the Environment, offers daily pet microchipping, online registration, deworming, vaccination, and neutering/spaying programs. Instead of sustainability, the One Health approach has been applied to address animal health as part of city priorities, including free-of-charge low complexity (pet vaccinations, microchipping, deworming, and antiflea treatment), medium complexity (neutering/spaying, pet ambulance, and emergency room attendance), and high complexity animal healthcare with a newly established public veterinary hospital. During the last four years (from 1 January 2021 to 31 December 2024), the city has promoted 266 free-of-charge neutering events, with a total of 48,290 dogs (18,923 males and 29,369 females) and 41,710 cats (17,954 males and 23,757 females) neutered and spayed. In addition, the Pet Food Bank City Program was created in 2019 (City Laws 15,449/2019 and 1,226/2019) and has provided 238,000 kg of pet food (over 836,000 meals) to 16 non-governmental organizations (NGOs) and 30 independent protectors. Since 2010, the city has promoted city adoption events in its biggest city park, providing a structure for NGOs and independent protectors, and has officially had 1,950 pets adopted (Secretaria Municipal do Meio, n.d.).

As part of the One Health strategy, a veterinary pet-mobile unit was created in 2018 in partnership with the Federal University of Paraná (UFPR) for residency training in shelter medicine, with around 23,000 dogs and cats brought by vulnerable low-income populations, which included clinical evaluation and procedures, deworming, antiflea treatment, rabies, and multiple vaccinations. In 2019, a veterinary ambulance was launched for city pets, particularly stray dogs and cats, with 3,400 rescues to date. In addition, a community dog program was established in 2014 in city bus stations, with healthcare and monitoring of diseases in around 30–50 dogs, including leishmaniasis, Chagas, and vector-borne diseases, as urban One Health sentinels (Constantino et al., 2017). The Curitiba Animal Protection Squad, started in 2014 and officially established in 2021, with four policemen and ten inspectors, receives and performs

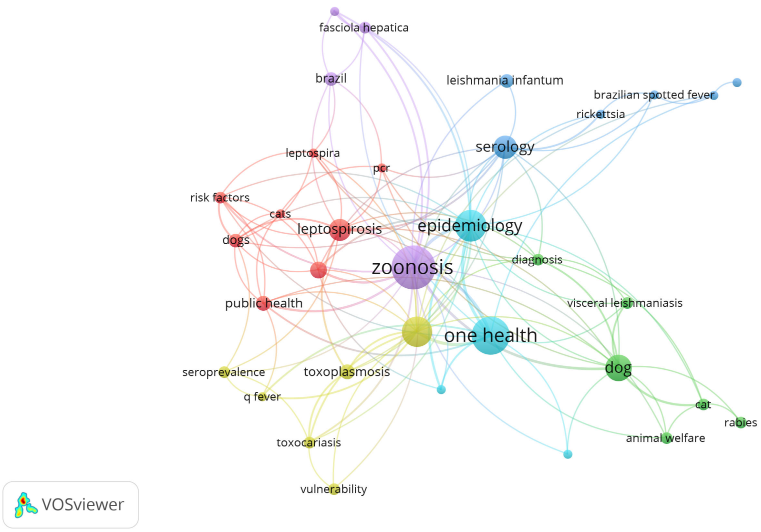

FIGURE 1
Bibliometric network illustrating the relationships between the main keywords in studies on zoonoses, One Health, and biophilia conducted in Curitiba, PR, Brazil.

approximately 5,500 animal cruelty inspections every year (Secretaria Municipal do Meio, n.d.).

The first city Public Veterinary Hospital was established in December 2024, distributed over an area of 68,467.05 m^2 and primarily attended by low-income individuals and animal protectors. One city hall council was elected for the 2025–2028 term and solely voted on the animal protection platform. Likewise, one federal congressman (currently working on his 2023–2026 term) was elected by the Paraná state exclusively on animal protection as a former state police chief of environmental crimes and animal cruelty.

As a result of its animal protection excellence, Curitiba was recently the 2019 winner of the top 10 best cities with animal protection policies in Latin America and the 2020 winner of the best pet-friendly city, both awarded by World Animal Protection (World Animal Protection, 2020).

8 Protecting urban wildlife fauna

The Curitiba Natural History Museum, established in 1963 as part of the Department of Animal Protection, Curitiba City Secretary of Environment, has a taxidermied collection of 7,000 mammals, 5,933 birds, 50,000 fish, 18,000 reptiles (mostly snakes), 12,000 amphibians (mostly Anura), 10,000 ectoparasites (including ticks/fleas/flies and lice), 70,000 insects, and 12,552 invertebrates (Curitiba P de, 2024c). The museum issued the city fauna inventory in late 2023, which, by city decree (1,082/2022), must be updated every 4 years (Curitiba, 2022a; Curitiba, 2020) (Supplementary Figure 4).

In 2019, the Reference Center of Native Fauna (RCNF) of Curitiba was established adjacent to the museum, with around 8,600 attendees of native species in its first 4 years of existence, mostly released into city parks after registration and appropriate care (Curitiba, 2024d). According to the official records of Curitiba, 10,000 wildlife specimens were examined at the RCNF in the first 5 years (from 2019 to 2023), with approximately 7,900 birds (79%), 1,700 mammals (17%), 400 reptiles (4%), and 16 amphibians. Mammals and birds were more likely to be received during late winter and spring, from August to November, with peaks in October and November, respectively.

The City Zoo, established in 1982, receives an average of 650,000 free visits every year and has guided day and night tours for elementary schools (Curitiba, 2024e). The zoo has become a sanctuary for native and exotic wildlife, receiving animals rescued and apprehended from illegal trade, road accidents, and climate events, such as major floods and forest fires nationwide (Curitiba, 2024e). In 2022, Curitiba Zoo was certified by the Brazilian Zoo Association and Wild Welfare for its institutional work in wildlife conservation and care, particularly for native fauna (Curitiba, 2022b).

Among hundreds of wildlife cared for and released monthly, a toucan rescued by a pet shop owner was received, treated, and released in Passauna City Park, one of the 49 major parks and green areas in Curitiba (Secretaria Municipal do Meio, n.d.) (Supplementary Figures 5–7).

9 Fighting zoonoses through biophilia

While the City Animal Protection Services, City Secretary of Environment, has focused on responsible guardianship and wildlife protection, the Zoonoses Surveillance Unit (ZSU), City Secretary of Health, worked on identifying, monitoring, and preventing diseases, particularly zoonoses. A combined decree of both secretaries (Environment and Health) was issued on 26 September 2014 to ensure coordination on overlapping activities such as outreach education, animal handling and training, zoonosis detection during rescuing, and wildlife preservation (Supplementary Figure 8).

In such a scenario, the ZSU has been controlling and preventing different zoonotic diseases, particularly rabies, mostly in bats and pets. Among the most fatal diseases worldwide, rabies is a growing public health concern in Brazil, as non-hematophagous bats may still potentially infect dogs and cats through spillover events, thereby increasing the risk of infection. Anthropization may have provided a predisposing environment for rabies transmission and overlapping contacts among humans, domestic animals, and wildlife. Although there have been no reported human or pet cases for almost three decades in Curitiba and São Paulo, several cases of bat rabies have been reported annually, showing viral circulation within city limits (de Lima et al., 2023). Recently, single cat rabies cases caused by bat-rabies variants were reported in both cities, probably due to cat hunting habits, preying on infected bats, and being found on the ground in daylight (de Lima et al., 2023).

As an alternative to systematically eliminating bats from Curitiba's urban areas, surveillance for bat rabies and associated risk factors for rabies spillover (even without human and pet cases) have been continuously monitored in Curitiba as part of the daily duties of the city's Zoonoses Control Unit. In a retrospective survey of 1,003 city requests for bat removal between 2010 and 2015, 806 live bats were collected and identified as belonging to 13 genera in three families, showing high urban bat biodiversity, as Curitiba has been classified as an 100% urban area (Ribeiro et al., 2018). Among them, 419/806 (52.0%) were considered healthy and were properly fed, provided water, and left overnight on a high-level shelf to fly away. Only 387/806 (48.0%) individuals considered unhealthy (including those not flying away) were sent for euthanasia and rabies testing, of which only 9/387 (2.32%) tested positive. The nine positive bats included two specimens of the genera *Molossus*, two of *Promops*, three of *Nyctinomops*, one of *Myotis*, and one of the genus *Sturnira* (Ribeiro et al., 2018) (Supplementary Figure 9).

Thus, although non-hematophagous bats may be involved in urban aerial and wildlife cycles, rabies disease in Curitiba has been monitored, controlled, and prevented with minimal wildlife disturbance and without bat biophobia. Non-hematophagous bats may have been one of the reasons why Curitiba has repeatedly won awards as the most sustainable city in Brazil and Latin America, as it biologically controls insects and small rodents without requiring insecticides, pesticides, baits, and traps. The Paraná State Reference Laboratory (LACEN-PR), located in Curitiba and responsible for rabies diagnosis, was given an award in 2019 as it was the first nationwide reference laboratory to replace the standard mouse inoculation test (MIT) with a novel duplex RT-qPCR protocol, ending the use of mice for rabies diagnosis (Minozzo et al., 2022).

Leptospirosis, the most lethal zoonotic disease in Curitiba with 4%–7% human mortality, has also been monitored and prevented by the ZSU by investigating probable infection sites for both notifiable human and dog cases, mapping and monitoring areas with a massive presence of synanthropic rats, monitoring flooding areas, and implementing educational strategies addressing healthcare professionals and occupational risk groups (Sohn-Hausner et al., 2023). In addition, rodents such as capybaras and nutrias live in major Curitiba city parks as their natural wetland habitats. Although there is no evidence of *Leptospira* spp. reservoirs in Curitiba to date (Ullmann et al., 2017), capybaras have seroconverted and presented up to 41.1% anti-*Leptospira* spp. antibodies in the microscopic agglutination test (MAT) in other Brazilian areas (da Silva et al., 2023). Thus, since some city parks have been used as natural pools to quickly control flooding, capybaras have been monitored and populations have been informed about leptospirosis and other zoonotic transmission risks.

BSF, the most lethal tick-borne disease in Brazil and worldwide, is another important zoonotic disease in Curitiba, as capybaras are reportedly considered the main tick-harboring species and disease reservoirs (G1, 2023). Curitiba has dealt with hundreds of capybaras and their ticks in city parks through wildlife population stability (decreasing transmission) and constant lawnmowing of their living areas and surroundings (decreasing tick spread), particularly when overlapping human pathways and trails. Thus, despite constant surveillance, no reports have been published to date on human or animal BSF cases within city limits.

Finally, other important nationwide endemic vector-borne zoonoses, such as leishmaniasis and Chagas disease, have not yet been reported in Curitiba, due to the lack of competent vectors and constant disease prevention. In such a free-of-disease scenario, human and canine visceral leishmaniasis has been prevented by active surveillance of seropositive dogs (main reservoir); investigation of dog and human autochthonous cases; vector surveillance, which includes trapping, confirmation of sandfly species, and molecular testing for *Leishmania* spp.; and educational door-to-door visits in high-risk areas to raise neighborhood awareness and knowledge that wildlife has no important role in the visceral leishmaniasis cycle (Ministério da Saúde, 2014). Likewise, Chagas disease prevention in Curitiba has been based on ZSU surveillance of kissing bug (triatomine) complaints by city residents, with vector identification and molecular testing for *Trypanosoma cruzi* (Ministério da Saúde, n.d.; Secretaria da Saúde, n.d.). In terms of sandflies, neighborhood visits have been planned to explain kissing bug habits and their prevention, particularly in nearby forest areas (Secretaria da Saúde, n.d.). In addition, environmental disturbances such as major fires, deforestation, and construction may stress wildlife fauna, such as opossums (*Didelphis* spp.), leading to the return of parasitemia, kissing bug infection, and disease spread (Roque et al., 2013).

Thus, zoonosis control, monitoring, and prevention in Curitiba can be safely achieved without biophobia and is based on active surveillance, field evidence, exposed population awareness, and prevention of animal cruelty in wildlife, synanthropic, and domestic species. Unsurprisingly, the city mascot is the capybara (Supplementary Figure 4).

10 One Health Index besides sustainability

A recent study assessed and compared human and companion animal health indicators in 29 cities in the Curitiba metropolitan area, directly obtained from the city secretaries of health and environment. Overall, higher animal protection perceptions were associated with higher city human development index (HDI), population, and income, whereas lower animal protection was related to cities with low income, higher social vulnerability index (SVI), and higher illiteracy (de Moura et al., 2022a). Thus, advanced community cities with better human health indicators also demanded better animal health actions, such as free city neutering/spaying programs, microchipping, animal cruelty inspections, and guardianship inserted into school content, as in the two handbooks available in Curitiba (Supplementary Materials 2, 7).

A One Health Index (OHI) was built by adding environmental indicators to the calculation and is defined as a comprehensive assessment of human, animal, and environmental health that could provide a specific city-, state-, or country-level assessment (de Moura et al., 2022a). In the analysis of the Curitiba metropolitan area, a higher OHI was associated with a higher city population and income, a shorter distance from the capital, and a tendency of low-income cities to present a lower OHI than higher-income cities, showing that the OHI may portray a comprehensive representation of a city's overall health. Despite the lack of animal and environmental indicators, the OHI has been used to compare South American countries (Sibim et al., 2024). Although within-country scales such as states and metropolitan areas (such as Curitiba) may better present contrasting differences, the OHI applied to South American countries has shown health and warming risks for forests and other natural areas, particularly the Amazon, which should provide proper incentives to promote sustainable economic growth aside from wildlife animal protection and environmental health (Sibim et al., 2024). Thus, animal (companion, livestock, and wildlife) health and welfare indicators may be considered part of local-to-global sustainability, using the OHI to calculate sustainability indices.

Considered a holistic approach, One Health has positively aligned human, animal, and environmental health, overlapping conservation and public health (Supplementary Figure 10) (WHO, n.d.). Biophobic responses to zoonotic pathogens have historically endangered wildlife host species and should be considered indicative of animal health and strategic sentinels of pathogen circulation and public health. Animal health, despite being a key component of the One Health framework, remains overlooked at multiple spatial scales, from local to international levels. Efforts to establish a global animal health index such as the Animal Protection Index (World Animal Protection, n.d.) have been hindered by insufficient official data, limiting the inclusion of many countries. Existing indicators, such as those for sustainability (World Animal Protection, n.d.) that focus on biodiversity, vegetation cover, and human health impacts from climate change, have not directly addressed animal health. As a result, countries often rely on indirect measures, such as zoonosis data and livestock health indicators (WOAH, n.d.), which have primarily focused on animal sanitation, neglecting companion and wildlife health and animal welfare (Sibim et al., 2024).

At local levels, such as municipalities, the absence of standardized data on the health of companion animals and wildlife further restricts the accurate assessment of animal health (de Moura et al., 2022a). Since human health systems and environmental health monitoring are generally more developed than animal health systems (Sibim et al., 2024), implementing a One-Health strategy at a local scale can significantly improve animal health. The relevance of zoonoses, such as COVID-19, highlights the importance of integrated approaches (Lefrançois et al., 2023). Municipal health systems, in collaboration with zoonosis surveillance units, can effectively enhance animal health outcomes, as already shown in southern Brazil (Leandro A de et al., 2021), and locally integrated strategies that address social challenges, such as animal hoarding and companion animal management, can further strengthen such efforts (de Moura et al., 2022b).

The OHI may overcome sustainability as an applied index for assessing the impact of daily systems, such as in automobile manufacturing. Despite the current global consensus that electric cars are friendly and advantageous for human and environmental health, no assessment has been made of animal health to date, as electric cars may silently hit more wildlife fauna crossing roads than regular cars. Nonetheless, current technology has provided ultrasonic devices emitting high-frequency sounds that disperse wildlife fauna but are inaudible to humans (Conservation Evidence, n.d.), which could be a standard OHI device for automobile manufacturing, saving the lives of millions of animals every year. In addition, fully transparent glass is used in the windows of cars, houses, and buildings, and walls are considered more environmentally beneficial for increasing visibility and saving internal lights (Supplementary Figure 11) (Window Stickers to Prevent Bird Strikes Only Work One Way). However, according to the American Bird Conservancy, such glass is responsible for billions of bird deaths due to collisions every year in the USA alone, according to the American Bird Conservancy (Schneider et al., 2018). However, stickers that are invisible to the human eye but are seen by birds can be developed and layered into regular glass manufacturing, helping prevent bird collisions (American Bird Conservancy, 2015; Window Stickers to Prevent Bird Strikes Only Work One Way).

11 Final considerations

Curitiba may be a successful example and model for the implementation of One Health, in addition to sustainability, highlighting the importance of animal health (domestic, synanthropic, and wildlife) in advanced cities. Despite the current fragmentation and degradation of biomes and ecosystems worldwide, intimate human-animal contact by multispecies families sharing indoor areas has become a new One Health challenge, with more Brazilian households having pets than children in the past decade. In addition, wildlife hunting, poaching, trading, and meat consumption, associated with zoonotic pandemics, have made zoonosis a major public health concern capable of lowering human life expectancy in modern times, as observed during the COVID-19 pandemic.

Such fear and avoidance of wildlife, passed on and reinforced through human generations, may justify the survival of biophobia over time, particularly in the urban settings of major cities. However, current global knowledge, technology, and connections must overcome zoonotic risks and replace fear and avoidance with wildlife protection associated with animal health and welfare, and under One Health, peaceful coexistence.

Zoonoses control, monitoring, and prevention should not be considered a synonym for biophobia, as wildlife affinity and conservation may be concurrently accomplished by zoonoses surveillance, considering wildlife fauna as vulnerable and as exposed to diseases as human beings. In such a scenario, wildlife species deserve equal veterinary care, assistance, wellbeing, and a long-lasting life in urban areas as in their original environment. In several cities worldwide, permeable asphalt has been designed, channeled rivers have been gradually opened, riverbanks have been revitalized, riverside flora have been reconstituted, and wildlife fauna have been preserved. Concrete backyards, squares, and sidewalks have provided space for native trees, green areas, and lawns. Slowly, fauna biodiversity may return to growth before it is too late. Such harmony should be pursued between human beings and domestic wildlife animal species (exotic and native) within a healthy urban environment, as a persistent One Health balance over thousands of years, as already achieved by ancient Brazilian indigenous peoples.

Author contributions

LK: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. CP: Conceptualization, Funding acquisition, Investigation, Resources, Visualization, Writing – original draft, Writing – review & editing. VM: Data curation, Investigation, Writing – review & editing. VN: Data curation, Investigation, Writing – review & editing. WC: Conceptualization, Data curation, Formal Analysis, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. PM: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AB: Conceptualization, Funding acquisition, Investigation, Resources, Visualization, Writing – original draft, Writing – review & editing, Data curation, Formal Analysis, Methodology, Project administration, Software, Supervision, Validation.

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Conflict of interest

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2025.1554076/full#supplementary-material

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Veterinary clinicians as One Health messengers: opportunities for preventing zoonoses while promoting biophilia in the United States

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One Health is a transdisciplinary approach to health science that recognizes the linked and interdependent ecology of environmental, human, and animal health. Effective communication of zoonotic disease risks through a One Health framework presents an opportunity to both prevent emerging infectious diseases and enhance public appreciation for wildlife and conservation, herein termed biophilia. While veterinary practitioners have historically played a pivotal role in public health and conservation, structural changes in the veterinary profession—including the dominance of companion animal practice, fee-for-service models, and corporate consolidation—limit their potential as One Health communicators, and thus wildlife conservation advocates. Additionally, the human-animal bond is often singularly framed as a health resource for pet owners and companion animals, neglecting its broader role within communities and its connection to other social, ecological, and epidemiological networks that include human and wildlife populations. This article outlines key constraints facing veterinarians as One Health communicators and proposes two solutions to integrate preventive zoonoses messaging and biophilia promotion within veterinary clinical practice: (1) the human-animal bond should be reconceptualized within veterinary clinical sciences as a community-level resource akin to natural capital, and (2) the veterinary extension workforce should be expanded to include agents facilitating local conservation and public health information exchange with companion animal veterinarians. Through these solutions, he veterinary profession can further enhance its principal role in One Health. Such efforts would empower veterinarians to communicate about zoonotic disease risks and conservation, ensuring that One Health principles are embedded in everyday clinical interactions and broader community initiatives.

KEYWORDS

veterinary medicine, one health communication, community practice, companion animal, human-animal bond, local conservation

Introduction

One Health is defined as 'an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and ecosystems. It recognizes the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent' (Adisasmito et al., 2022). Biophilia, as posited by E.O. Wilson, describes the process explaining 'to the degree that we understand other organisms, we will place a greater value on them, and on ourselves' (E.O., 1984). One Health enables a biophilic approach for messaging zoonoses risk by emphasizing the shared ecology of infectious disease and conservation management tasks. More specifically, One Health offers a sustainable strategy to prevent wildlife borne zoonoses while preserving public regard for wildlife and nature by providing a conceptual framework for practitioners to speak in a unified voice (Destoumieux-Garzon et al., 2018; Kirkey, 2024; Reaser et al., 2025). Further, while prevention of emerging infectious disease is often presumed to be delegated to tropical and subtropical regions, the United States and Europe contain tremendous biodiversity in proximity to changing landscapes where human contact with vectors and zoonotic reservoirs still affects spillover risk (Patz et al., 2004; Randolph, 2001). For example, in early 2025 University of Rochester in collaboration with the United States Centers for Disease Control and Prevention identified a novel Henipavirus with zoonotic potential in Northern Short Tailed Shrews sampled from Alabama (Parry et al., 2025). The perceptive axiom balancing zoonoses risk perception and biophilia can be further observed through concern for zoonotic disease origins in wildlife leading to culling, pest management strategies, and zoonoses risk and animal welfare perception affecting food purchasing decisions (Anderson and Reaser, 2024; Stel et al., 2022; Decker et al., 2010). Despite these dynamics, the impact of zoonoses risk perception on biophilia is sparsely defined across community types, and there persists a variable public understanding of endemic zoonoses (Oruganti et al., 2018; Paul et al., 2010; Eisen et al., 2017; Sandhu and Singh, 2014).

The effective responsibility for linking veterinary public health with conservation lies on public institutions, including universities, while operational support for grass roots actors such as veterinary clinicians is largely neglected (Hassan et al., 2023). Notwithstanding the importance of top-down communication and programmatic campaigns, clinical veterinarians (herein termed 'clinicians') moderate significant interactions with community members about zoonoses arising from wildlife (Chakraborty et al., 2024). Further, the rising emphasis on the human-animal bond, a phenomenon in the United States and globally, presents an opportunity to leverage the clinician-client interface for One Health and conservation messaging (Chakraborty et al., 2024; Mendez et al., 2017). In short, clinicians possess tremendous potential to strengthen local conservation and community health goals – they just need the time, energy, and support to do it. Reducing zoonoses and promoting biophilia via the domestic veterinary workforce is a bottom-up strategy that can generate cultural momentum in tandem with other strategies. Here, I outline contemporary barriers and succinct opportunities linking veterinary clinicians to this challenge.

Constraints to One Health communication in a rapidly changing profession

The veterinary profession formally emerged at the turn of the 20th century from state directives that recognized public need for systematized equine health services, as demanded by urbanization and industrialization, and evolved in the coming decades to combat agricultural epidemics (Greene, 2010). Species targeted in clinics mirrored those in regulatory practice, emphasizing farm animal and equine care (Smith, 2013). Regulatory veterinarians also began supporting state fish and wildlife programs as early as the 1940s, and further at federal programs in the 1960s (Congress, 1914). The programmatic attention to wildlife disease and zoonoses at agricultural and varied environmental interfaces, signifies an inchoate One Health paradigm that would evolve further in the latter half of the century as landscape and ecological drivers of disease began to be recognized.

In the late 1900's, the dominant veterinary professional pathway shifted to dog and cat health and today pets in America demand more attention than ever, creating an industry that is a diverse ecosystem experiencing fast change within itself (Smith, 2013). Now, the majority of veterinarians become small animal clinicians, and at the heart of veterinary career incentive structures rests a large clot of veterinarian student debt (AVMA, 2024; Lairmore et al., 2024). Companion animal practice, particularly specialty services, boasts the highest average salary amongst other practice areas and skews career choice away from farm animal, public service, and other career pathways based on fiscal pressure (Bain and Lefebvre, 2022).

Despite the pull of private markets, through veterinary training, One Health is addressed as a conceptual paradigm with support from many public service programs but nests implementation within veterinary clinics at the level of the time and emotional resource constrained practitioner (Janke et al., 2021). In the dominant fee-for-service clinic model, financial pressure may negatively impact non-financially incentivized tasks, where practitioners must individually and proactively strategize extra-patient priorities (Deluty et al., 2020; Lloyd, 2013). Like human healthcare, fee-for-service models can lead to over-utilization of services, higher costs, fragmented care and disincentivizing non-monetary action such as community engagement on broader issues in the field, such as 'Preventing Zoonoses. Promoting Biophilia' (Baker, 1997; Dowd and Laugesen, 2020). The Veterinarian-Client-Patient relationship (VCPR), as a legal definition, does not specify wildlife and ecosystems as stakeholders for veterinary practice decisions, although the veterinarian's oath includes a commitment towards conserving animal resources (AVMA, 2003; Veterinary Oaths). Additionally, veterinarians are among the highest at-risk health profession group for burnout, depression, and self-harm due to a multitude of factors speculated to be intrinsic to the field and the personality characteristics it tends to attract (Nett et al., 2015; Stetina and Krouzecky, 2022). Without structural support, One Health communications are at risk of adding to veterinarian brain drain and increasing veterinarian migration from low to high resource settings as seen in human healthcare (Dohlman et al., 2019).

Further, the veterinarian's position broadly as a community pillar and autonomous business owner is somewhat existentially challenged by the rise in corporate veterinary practice ownership (Kogan and Rishniw, 2023; Steinbach, 2023). While veterinarian owned small businesses persist, corporations have consolidated impressive margins of the market and, by affect, hold tremendous influence over veterinary practice norms and business strategies. In 2021, it was estimated that nearly half of all companion animal clinical revenue in the United States arose from corporate practice (Kogan and Rishniw, 2023). Many clinicians are skeptical that the stakeholder power generated through consolidated ownership and private equity will guarantee higher quality of care and fair prices, although benefits such as predictable hours and higher institutional resources could benefit One Health messaging in corporate contexts (Ruiz, 2019; Smither, 2015; Kogan and Rishniw, 2023). In 2023, Kogan et al. found that 12% of veterinarians in their survey (n=896) preferred working for corporate practice, compared to 55% who preferred private practice (Kogan and Rishniw, 2023). While there is some evidence that corporate environments may currently offer lower pricing schedules, the rise of dominant market ownership may threaten future competitive pricing, as has been seen by other industries including human healthcare (Khan, 2021; Dafny, 2021; Kogan and Rishniw, 2023). Consolidation is also under growing scrutiny from the wider public, as seen by the publication of 'Big Vet' articles in The Atlantic, CBS News, and Bloomberg, highlighting the importance of community-focused veterinary service delivery (Carrol, 2023; Novak, 2025; Bryant, 2023; Olen, 2024). Notwithstanding the uncertain impact of these trends on financial accessibility to and public perception of veterinary services, it remains to be seen if corporate practice will effectively leverage the veterinarian to accomplish non-financially incentivized tasks in benefit of the broader public.

Despite these trends, domestic animals still introduce conservation hazards and embody risk arising from wildlife and natural environments (Mendoza Roldan and Otranto, 2023). Standard prevention protocols for dogs and cats target multiple pathogens arising from peri-domestic wildlife or arthropod vectors, and the ecosystem impact of free-roaming and feral dog and cat populations through predation of small mammals and birds is widely recognized, driving local extinction in some cases (Silva-Rodríguez and Sieving, 2012; Medina et al., 2011; Twardek et al., 2017; Day et al., 2012). Companion animals and livestock may also become a prey source for large carnivores, increasing human-wildlife conflict and threatening biophilia (Hughes and Macdonald, 2013). To complicate management, the variability of public perception of free-roaming domestic animals often obstructs regulatory support (Lord, 2008). The agricultural sector may be a step ahead and addresses risks posed by the domestic-wildlife interface by supporting agriculture extension agents work closely between industry and university veterinary medicine and animal science departments to provide producers with evidence based communications, often through a One Health lens. Analogous interface between companion animal stakeholders has not been widely adopted. Some pet health programs explicitly incorporate a One Health paradigm into general practice to link patient and client care with broader community health concerns, such as those through the University of Washington, University of Minnesota and more broadly through zoo education programs (Minnesota, 2025; Washington, 2018). However, such programs often operate as non-profits relying on subsidies or fixed-payment structures and may not provide a viable solution for veterinarians in fee-for-service settings (Blackwell and O'Reilly, 2023; Coalition, 2018, Garabed et al., 2022).

Contemporary representation of Human-Animal Bond

The expansion of companion animal clinical practice in the United States is also moderated by the increasing emphasis of the Human-Animal Bond (HAB), and more specifically the human-pet bond, a dynamic deserving unique attention. Research of the HAB indicates pet ownership benefits to mental and physical health, although there is need to standardize metrics across research (Rodriguez et al., 2020; Ellis et al., 2024; Michigan, 2019, Sara Hussein, 2921). Human-animal relationships, directly and via zoonoses, have long been powerful representations in contemporary art, seen in contemporary productions such as Netflix's "Sweet Tooth" and the recurring tropes in Wes Anderson's filmography (Asenath and Santhanalakshmi, 2021; Martinelli and Lankauskaitė, 2022; Sadaf Ashraf and Farooq, 2024). Within this context, veterinary practice benefits from the rise of the HAB, as pet owners become increasingly concerned with pet health outcomes and the positive impacts owning pets may bring. The increased veterinary business opportunities may further improve animal welfare by increasing clients' veterinary care seeking behaviors (Rault et al., 2020). Veterinary health corporations include purported benefits within their communication campaigns and often conduct their own client surveys research that underline their prioritization of this relationship (Hospital, 2020, 2016). Veterinary care advancements often accompany cultural shifts towards individual pet ownership, which can be observed globally, too, as veterinary clinical markets emerge alongside economic development (Parlasca et al., 2023; Mohamud et al., 2023; Gizaw et al., 2023).

However, in its current formulation in the veterinary services industry, the HAB nests benefits at the level of the individual relationship – i.e. between companion animals and their caretakers – without drawing on the benefits of the HAB to communities and ecosystems. This isolates veterinary patients and clients from the networks within which they live, decreasing the practitioner's opportunity to communicate through a One Health lens. Without recognizing the broader context of veterinary disease and interspecies contact networks, management of this relationship in the clinic will not be sustainable at scale (Curran, 2017). Future veterinary public health research and business strategies should prioritize evaluating community impacts of human-animal relationships, such as the cumulative impact of pet ownership and veterinary health behavior and health promotion on sociology (rather than psychology) and broader human-nature relationships - expanding the paradigm of the HAB to routinely include wildlife and shared ecosystems as stakeholders within the veterinary healthcare community (Andersen et al., 2013). This approach recognizes that the human animal bond is a shared resource and thus can be situated closer to the base of the health impact pyramid, where structural and socioeconomic interventions can provide more effective upstream strategies, similar to zoonoses risk communication and other biophilic messaging (Frieden, 2010).

Solutions

Current trends leave a gap for biophilic conservation and One Health messaging within clinical practice, where currently the time, energy, and resource constrained practitioner currently must strategize their own approach to these goals. Opportunities exist for academic training and professional pipelines to adapt and I present the following solutions as logistically feasible near-term opportunities to provide support for the veterinarian's responsibility to serve as One Health and wildlife conservation messengers.

Human-animal bond as natural capital

Natural capital refers to the 'living and nonliving components of ecosystems – other than people and what they manufacture – that contribute to the generation of goods and services of value for people' (Guerry et al., 2015). Domestic animals represent a link to ecosystems with dual trade-offs. Pets may bear risk via wildlife borne disease, including zoonoses, from entering wild areas – as such is the case for hunting, sledding, and other working dogs – but they may also introduce risk to wildlife through potential ecosystem disturbance (Crowley et al., 2020; Toepp et al., 2018). Characterizing the human-animal bond without recognizing the broader context of veterinary disease and community networks will prevent sustainable development of clinical management strategies at scale (Tam et al., 2013). Zoonoses prevention and the promotion of biophilia are resources that provide value through protection of health and nature – which is more easily conceptualized as the absence of a hazard, such as pathogen infection, human-wildlife conflict, or domestic animal-wildlife conflict, respectively. Thus, a paradigm shift in veterinary profession recognizing the human-animal bond as a resource akin to natural capital, will have a downstream positive impact on the veterinary clinician's ability to communicate about zoonoses through a biophilic lens (Munawar, 2024). Such representation has been advanced in the sustainability and social sciences, but it has not yet been widely adopted within veterinary public health research and clinician training, where instead the market perceptively drives HAB implementation (Konstantinova et al., 2021).

Future research should aim to clarify the value of the human-animal bond at community levels by strengthening links between appropriate socioeconomic measures, cultural values, and ecosystem health with veterinary management strategies. Future epidemiological studies may incorporate methods native to ecology and social sciences, such as participatory pathway analysis, to conceptualize how the human-animal bond impacts health and population management strategies and changes over time (Su et al., 2024). Community and veterinary focus group meetings with standardized criteria for feedback evaluation, such as weighted sum or weighted product models, may be used to engage communities, rank stakeholder priorities, and thus ensure sustainable veterinary service development (Puska et al., 2022; Ayan et al., 2023). Implementation and evaluation at local scales underscores the need for additional extension infrastructure serving public health, veterinary clinician, and wildlife stakeholders in tandem. With appropriate planning, such approaches could simultaneously advance local and state initiatives for conservation and public health management, as they relate to veterinary clinical practice.

Extension positions for one health engagement at companion animal practice

Veterinary extension programs emerged at veterinary and animal science colleges as cooperatives between academic institutions, industry, and state and federal agricultural departments to advance agricultural and public health through dissemination of research and technical information (Congress, 1914). Analogous work targeting companion animal practice would empower the pet health sector to appreciate One Health, local zoonoses risk, and local conservation issues. Importantly, providing structural support for such communications elevates responsibility for generating locally contextual One Health messages from individual clinicians to the business and regulatory structures that support veterinary health deployment. Extension agents would serve veterinary clinics directly and the broader community with messages emerging from timely science and regulatory directives. Extension positions should be placed at academic or state government institutions and funded through good faith co-sponsorship of various private business, corporate, professional organization, and government (including academic) sources that seek to moderate the deployment of veterinary services for various private and public goals.

A third-party agent simultaneously avoids putting additional strain on the time constrained practitioner while contributing infrastructure that delivers non-monetary incentivized services to the community. Candidate strategies could be identified centrally through extension programs and then specified to local clinical contexts. For example, Reaser et al. propose a 'Love Them and Leave Them' messaging campaign to prevent zoonoses and promote biophilia (Reaser et al., 2025). Environmental psychology has also posited numerous design strategies for incorporating biophilia into servicescapes, and art demonstrations may be used to facilitate a nuanced and further reaching community footprint (McGee and Marshall-Baker, 2015, Beaumont, 2024). With adequate time and energy resources, increased engagement in One Health and biophilic messaging may also help veterinarian efficacy and increase emotional rewards, and support resources would avoid adding on to burnout (Clise et al., 2021). Systematic tracking of clientele and veterinary attitudes within locally catered and standardized program evaluations would work align this model with federal strategic frameworks aiming to expand the One Health workforce (Stel and Banach, 2023; Behravesh et al., 2023).

Discussion

The veterinary profession is experiencing growth that highlights the dominance of companion animal clinical practice career pipelines, fee-for-service models, and the rise of corporate practice. These trends incidentally may limit the reach of veterinarians as One Health communicators. I propose two solutions to support the companion animal veterinarian's role as a One Health communicator. First, the veterinary clinical sciences, namely through academic training institutions, should advance the conception of the human-animal bond as a community resource similar to natural capital, rather than a phenomena solely benefiting pets and pet owners. Broadly, this recommendation could be seen as an analogous effort to communities creating more human-nature interactions – such as the urban planning of green and blue spaces, primary school programs exposing students to nature, and know-your-farmer programs – and aligns with the American Association of Veterinary Medical Colleges recognition of One Health as a strategic approach towards advancing global well-being (Flint, 2013; AAVMC, 2014; Kim et al., 2021; USDA, 2016). Second, industry and public co-sponsored veterinary extension positions should be placed at veterinary colleges or state agencies to disperse One Health and conservation information to clinical practices. These actions allow for the continued development of the veterinary profession while increasing the stakeholder power of veterinary clinicians as community members and experts in science and health practice. Such action aims to provide nested space and strategy for organizing research and cross-sectoral allocation of resources, which is a primary constraint when operationalizing One Health goals (Destoumieux-Garzon et al., 2018).

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MO: Conceptualization, Writing – original draft.

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Conflict of interest

The authors declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Application of the MENTOR model to advance One Health by promoting bat conservation and reducing zoonotic spillover risk

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For few taxonomic groups do conservation efforts have such a disproportionate impact on biodiversity and human well-being as they do with bats. Bats face significant conservation challenges that affect their long-term viability, inhibit their ecosystem functions and services, and increase zoonotic spillover risks. Protecting bat populations and their habitats ultimately reduces these conservation threats, helps prevent pandemics, and supports essential ecosystem services. MENTOR-Bat is a fellowship program focused on strengthening technical research, and leadership capacity in the Global South to promote healthy environments where bats and humans can coexist with reduced risks of pathogen transmission. Co-designed by the United States Fish and Wildlife Service (USFWS) and Bat Conservation International (BCI), MENTOR-Bat mirrors the One Health framework by featuring a transdisciplinary team of three mentors and nine fellows from Cameroon, Colombia, and Indonesia. Fellows and mentors receive academic and field-based training on bat ecology and conservation, One Health, human dimensions of conservation, behavior change, strategic communications, international policy, adaptive management, project planning, conservation leadership, and public health. Fellows will then design and implement team pilot projects to advance One Health and bat conservation in their respective countries. Program evaluation of MENTOR-Bat is based on Kirkpatrick's Hierarchy and focuses on measuring the development of established One Health core competences. By incorporating One Health and conservation within its activities, MENTOR-Bat can become a valuable programmatic template for transdisciplinary programming advancing evidence-based strategies for improving the well-being of bats, humans, and the environment.

KEYWORDS

capacity development, spillover, nature-based solutions, conservation leadership, curriculum

Introduction

Bats are a highly diverse order of mammals found across the world and are facing major conservation threats including land-use change, disturbance, disease, hunting, and climate change (Frick et al., 2020). Some bat species can be reservoir hosts to zoonotic pathogens, meaning that they naturally harbor these pathogens and serve as a source of them (Luis et al., 2013; Brook and Dobson, 2015; Johnson et al., 2020). Following sporadic outbreaks of Nipah Virus in South Asia, the 2002 SARS epidemic, Marburg virus in Central Africa, and the COVID-19 pandemic, fear of bats increased due to expanding awareness of zoonotic spillover risks (Lu et al., 2021; Ejotre et al., 2022; Nanni et al., 2022; Straka and Voigt, 2022; Osofsky et al., 2023). Pressures like habitat disturbance and climate change further increase the risk for zoonotic spillover: as bats become stressed, they are more susceptible to infection and increased pathogen shedding (or releasing pathogens into the environment via excrement or saliva) (Plowright et al., 2024). Many of these threats also increase the potential for contact between bats and humans, which also increases the risk for zoonotic spillover (Eby et al., 2023; Plowright et al., 2024).

One Health, which recognizes that animal, human, and environmental health are interdependent and must be promoted simultaneously, can be used to promote biophilia, or a desire to connect with nature. As the world emerges from the COVID-19 pandemic, bat and biodiversity conservation must be promoted writ large to reduce zoonotic spillover risks and prevent pandemics before they begin (Eby et al., 2023; Weber et al., 2023; Plowright et al., 2024; Reaser et al., 2024). Protecting bat populations and their habitats offers significant co-benefits for people and bats; these activities reduce stress and viral shedding in bats while also reducing human-bat interactions. This provides primary prevention of pandemics by reducing the risk of pathogens emerging in the first place. This protection also preserves functioning ecosystem services like pollination and insect control. As key ecosystem players often persecuted due to fear of disease, bats exemplify the need for a One Health approach and biophilia promotion.

Bat diversity is highest in equatorial regions, which are also hotspots for zoonotic diseases and where the bat species known to be zoonotic reservoirs are most commonly found (Schneeberger and Voigt, 2015; Guth et al., 2022).

Activities such as hunting bats for meat consumption or wildlife trade (Latinne et al., 2020; Tanalgo et al., 2023), guano harvesting (Thet and Mya, 2015), cave tourism (Chiarini et al., 2022), and persecution (Schneeberger and Voigt, 2015), which bring people into close proximity with bats, are prevalent in these regions. To address the risks posed by these activities, researchers emphasize the need for integrated approaches that combine biodiversity conservation and public health efforts (Glidden et al., 2021). Strengthening the capacity of conservation and public health leaders in these regions is crucial not only for protecting these species but also for preventing zoonotic spillover (Amuguni et al., 2017). While programs exist that promote either conservation or public health, few address both simultaneously, highlighting a critical gap in the integration of these efforts. Education and collaboration between conservationists and other sectors are crucial for preventing future zoonotic outbreaks and protecting bat populations.

MENTOR-Bat is a fellowship program that builds upon previous U.S. Fish and Wildlife Service (USFWS) MENTOR conservation initiatives, focusing on enhancing the technical, research, and leadership capacities of early-career professionals from the Global South in promoting both conservation and public health. Co-designed with Bat Conservation International (BCI), a science-based, not-for-profit, non-governmental organization (NGO), the program aims to equip fellows with the skills needed to design, implement, and sustain One Health conservation initiatives that protect bats and their habitats while reducing pandemic risks.

The United States Fish and Wildlife Service MENTOR model

Since 1989, the USFWS International Affairs Program has supported over 700 partner organizations to protect wildlife and key wildlife strongholds while developing conservation champions. Recognizing that capacity development is critical for conservation success, USFWS International Affairs launched the Mentoring for Environmental Training in Outreach and Resource Conservation (MENTOR) Program in 2008 to train professionals in technical competencies to promote evidence-based approaches to conservation (Abu-Bakarr et al., 2022). The MENTOR model combines academic and field-based approaches through experiential learning, training, conservation planning, project implementation, mentoring, and problem solving. Fellows earn post-graduate degrees, diplomas, or certificates from national and regional colleges and universities.

Through seven programs, USFWS MENTOR has supported 61 fellows from 11 African countries, fostering conservation leadership across issues including the bushmeat trade, extractive industries, fisheries management, and manatee, great ape, and pangolin conservation (Abu-Bakarr et al., 2022). Alumni of the program have gone on to lead conservation initiatives within governments, NGOs, and the private sector; perform research; manage national parks; and become mentors themselves for new conservationists. They are contributing to long-term conservation leadership and capacity development within program countries and internationally (Abu-Bakarr et al., 2022).

MENTOR-Bat is the first multiregional iteration of the USFWS MENTOR Programs and spans three continents with cohorts from Cameroon, Colombia, and Indonesia. Under the American Rescue Plan Act that the U.S. government enacted in response to the COVID-19 pandemic, USFWS received funding "for research and extension activities to strengthen early detection, rapid response, and science-based management to address wildlife disease outbreaks before they become pandemics and strengthen capacity for wildlife health monitoring to enhance early detection of diseases that have capacity to jump the species barrier and pose a risk in the

United States". USFWS International Affairs recognized the opportunity to apply the MENTOR model by establishing transdisciplinary teams aimed at reducing high-risk interactions between humans and bats while promoting bat conservation (The American Rescue Plan Act, 2023). The program advances the established USFWS MENTOR Model of connecting transdisciplinary teams of fellows with long-term mentors, senior conservation leaders, and international experts who guide the fellows, teach problem solving techniques, and foster the development of creative solutions in learning partnerships that continue throughout the careers of both mentors and fellows.

MENTOR-Bat program structure

Each country MENTOR-Bat cohort consists of three fellows and one mentor, selected through a competitive application and interview process. Each mentor is a bat ecology, behavior, and conservation expert while fellows come from an array of backgrounds, including ecology, wildlife conservation, veterinary medicine, virology, environmental education, geology, and public health. The eighteen-month program consists of virtual learning; in-person workshops; pilot project design and on-the-ground project implementation in program countries; educational outreach about bat conservation and One Health in program countries; a final in-person MENTOR-Bat Outcomes Workshop; and a MENTOR Forum on conservation leadership. The project structure is as follows:

1. During the initial five months of virtual curriculum, experts present on topics including bat conservation, One Health, human dimensions of conservation, outreach and communications, adaptive management, conservation leadership, and others.
2. Fellows complete assignments on the major themes of the curriculum that are reviewed by their national mentors.
3. Punctuating the first five months of virtual learning are two workshops that emphasize team building, including a launch workshop in Colombia and a workshop in Indonesia where the cohorts will learn the conservation standards and adaptive management to design their pilot conservation projects.
4. During the remaining thirteen months of the program, fellows conduct field site visits, design and implement field-based pilot conservation projects and meet with government ministries and NGOs to mobilize their projects in their respective countries.
5. They will educate domestic stakeholders in their country about MENTOR-Bat and their projects, and advance conservation and educational outreach about bat conservation and One Health during Bat Week in October 2024 and International Bat Appreciation Day in April 2025.
6. The final step in the program will be the MENTOR-Bat Outcomes Workshop and USFWS MENTOR Forum. This will take place in Cameroon where MENTOR-Bat cohorts will present their pilot project outcomes and earn a certificate from Garoua Wildlife College, the leading regional Francophone training institution for wildlife managers. Fellows from previous MENTOR programs will attend with MENTOR-Bat fellows to discuss implementing conservation leadership to address threats to wildlife and grow the active MENTOR Network of conservation champions. Since many mentors and fellows are advanced in their careers as well-recognized conservation leaders, they design and lead the Forum as an opportunity to share lessons, technical expertise, learning on conservation leadership and threats to wildlife, networking and to inform recommendations for future MENTOR programs and similar capacity development initiatives. This will also grow the active MENTOR Network of conservation champions.
7. Upon completion of the program, fellows are encouraged to build upon their network and skills gained in MENTOR-Bat to maintain connections with USFWS and BCI to continue as bat conservation and One Health champions in their countries.

MENTOR-Bat launched in Colombia in April 2024 and cross-cutting themes emerged across the cohorts, including a passion for community education on bat conservation and healthy coexistence; understanding how ecological pressure on bats can increase zoonotic disease spillover risks; and building an international network of professionals who are interested in and passionate about bat conservation and community outreach for coexisting with bats.

Why MENTOR-Bat is needed

Many bat conservation programs do not incorporate public health initiatives or zoonotic spillover risk reduction messaging. Conversely, many public health campaigns advise people to avoid contact with bats without also educating about their ecological benefits and how safe coexistence is possible, which ultimately hinders conservation efforts. Few programs simultaneously promote biophilia and enhance pandemic prevention, despite their interconnection.

Successfully promoting conservation and zoonotic spillover risk reduction together is challenging. After bats were identified as the potential source for spillover of SARS-CoV-2 that led to the COVID-19 pandemic, some countries culled bats (Lu et al., 2021). While these actions were intended to reduce bat populations near people, they created additional risk by elevating the potential for bat-human contact during culling (Lu et al., 2021). While there was no report of a second spillover of SARS-CoV-2 from bats, this strategy likely increased the risk of this happening rather than reduced it. Bolstering global health security is often framed within strategies such as stockpiling medical countermeasures and building health systems capacity. While these are certainly needed to strengthen disease outbreak and pandemic response, they are downstream, secondary prevention approaches that focus on responding to an outbreak long after a disease has emerged and is spreading through a human population (Plowright et al., 2024). With 75% of emerging infectious diseases originating in animals, the world must also advance upstream strategies to prevent spillover and pandemics from occurring in the first place (Shaheen, 2022). Such nature-based primary prevention strategies for pandemics have significant shared benefits for humans, animals, and the environment and are estimated to cost a mere 1% of what it costs to respond to a pandemic (Bernstein et al., 2022; Plowright et al., 2024). Primary prevention of pandemics also costs less than $1/20^{th}$ of the value of human lives lost each year to emerging viral zoonoses (Bernstein et al., 2022).

Nature-based strategies to prevent the spillover of bat-borne pathogens and consequent disease emergence can be broadly grouped into three countermeasures: protecting where bats roost, protecting where bats forage, and protecting people at risk (Plowright et al., 2024). These countermeasures function through two general mechanisms: 1) reducing the risk of pathogen infection and shedding in bats by ensuring that access to high-quality food and shelter is readily available and that they are not under allostatic overload, and 2) reducing opportunities for pathogen exposure to people or livestock in close proximity to bats that could serve as potential pathogen reservoirs (Kessler et al., 2018; Eby et al., 2022; Plowright et al., 2024). Examples of these countermeasures include protecting and restoring bat foraging and roosting habitats, working with stakeholders who have close contact with bats through economic and livelihood activities (e.g., guano harvesters, cave tourists, people who hunt and consume bats) to adopt safe practices that reduce both stress and disturbance in bats while minimizing opportunities for pathogen exposure, and raising awareness about the ecological and economic roles of bats. Involving stakeholders in the strategy development and decision-making process, as well as raising awareness can inform people's attitudes toward bats, encouraging them to become stewards of bats and their ecosystems rather than persecuting them out of fear of disease. By implementing strategies grounded in bat and ecosystem conservation, as well as education on safely coexisting with bats, MENTOR-Bat aims to build capacity for the primary prevention of potential future pandemics.

Discussion

Program evaluation of previous MENTOR programs

In a previous study, mixed methods including a survey, key informant interviews, and a document review were used to evaluate the efficacy and impact of the series of USFWS MENTOR programs. The study found that: 1) previous MENTOR programs played an important role in helping fellows establish and expand their professional networks, 2) all participating fellows confirmed that they acquired new skills and knowledge, and 3) all fellows felt that their MENTOR participation improved their professional development (Abu-Bakarr et al., 2022). Adaptive management was found to be a consistently improved competence, as well as use of information and communication technology, leadership, and conservation outcomes. The transdisciplinary focus of MENTOR programs was found to enhance team building and inspire fellows to develop long-term professional networks. To address One Health challenges, building enduring multidisciplinary networks across sectors is crucial for sustainable capacity development. By exposing fellows to the complexity of challenges at the One Health interface, MENTOR-Bat aims to enable fellows to become competent professionals who will be capable of fostering connections across sectors. In MENTOR-Bat, 51 instructors and supporters from 33 different organizations provide guidance and link cohorts to additional professional networks like the Global Union of Bat Diversity Network (GBatNet), further enhancing their professional growth and network expansion.

Evaluation of One Health core competences

MENTOR-Bat's curriculum is based on the nine One Health core competences identified by the United States Agency for International Development (USAID)/RESPOND project multiagency working group as necessary to include in One Health training programs (Amuguni et al., 2019).[1,2] These are project management; communication; gender, culture, and beliefs; leadership; collaboration and partnership; values and ethics; systems thinking; policy and advocacy; and research (Amuguni et al., 2019). MENTOR-Bat has designed its program curriculum and evaluation methodology around these One Health core competences, and conducted a knowledge, attitudes, and skills (KAS) survey during the launch workshop in Colombia in April 2024 that evaluated the fellows on these core competences.

Program evaluation methodologies

To evaluate program efficacy, MENTOR-Bat is using Kirkpatrick's Hierarchy, which consists of four levels of evaluation: reaction, learning, behavior, and results (Alsalamah and Callinan, 2021). Reaction measures fellows' engagement and how well training content was received by administering post-training evaluation surveys that will provide feedback to MENTOR-Bat staff on the program's content and delivery. Learning measures how the training has developed fellows' knowledge, skills, attitudes, and their confidence in implementing what they have learned. Learning will be measured at the beginning and end of the program through surveys and will test MENTOR-Bat's pre-defined core competences. Behavior measures whether the

1 RESPOND was a component of the USAID Emerging Pandemic Threats (EPT) Program.

2 The Africa One Health University Network (AFROHUN), formerly One Health Central and Eastern Africa (OHCEA), collaborated with the Southeast Asia One Health Network (SEAOHUN) and a multiagency Global One Health Core Competency Working Group to determine and establish a list of core competencies that One Health training programs should include.

fellows have applied their learning, which is best measured several months after the training has been completed and can be done in the form of interviews. Results measures the outcomes of the program and will be based on the implementation of national cohorts' projects and two programmatic activities: the MENTOR-Bat Outcomes Workshop and the national cohorts' presentations to relevant stakeholders (i.e., NGOs, government agencies, local communities, and others) (Alsalamah and Callinan, 2021).

Post-training evaluation surveys will be delivered at the end of the academic training. There are four surveys grouped by the following themes: bat conservation, One Health, human dimensions, and outreach. The Conservation Leadership Programme (CLP) will lead the conservation leadership training portion of the program and will implement their own post-training survey. The survey results will be used to inform future MENTOR programs and can inform future One Health capacity development programs and other similar programs. Results from these surveys will be analyzed and published in a peer-reviewed journal and MENTOR-Bat fellows and mentors will be invited to participate in the publication. Fellows were notified at the beginning of the program about the goals of the post-training evaluation surveys and the intended use of the associated data. Fellows who decide to participate were asked to sign acknowledgement of the goals of the surveys, intended use of the data, and willingness to participate in the surveys. Anonymity and confidentiality will be maintained and ensured, with unique identifier codes used when responding to surveys. The unique identifier codes will be used throughout the program to evaluate fellows' individual progress throughout the program without disclosing their identity. International human subjects research standards will be followed.

Anticipated impacts on One Health capacity development

MENTOR-Bat is designed to promote primary prevention of pandemics that aims to stop outbreaks before they start by mitigating spillover risks through a One Health approach. The world currently prioritizes biomedical responses to existing disease outbreaks over primary prevention, which can be costly and ineffective. This approach naturally lacks a focus on achieving co-benefits for conservation and sustainable development, whereas MENTOR-Bat aims to prioritize these co-benefits.

Embedded within the strategies for promoting primary pandemic prevention, one of the goals of MENTOR-Bat is to reduce the stigmatization of bats and promote their conservation. Achieving this can create a positive feedback loop for spillover prevention strategies, as many situations that bring people into close contact with bats result from the persecution of bats due to fear of disease (MacFarlane and Rocha, 2020; Rocha et al., 2021). Additionally, encouraging people to safeguard the ecosystems they share with bats can support efforts to maintain healthy bat populations with a low risk of pathogen infection and shedding (Plowright et al., 2024). Focusing on the benefits of bats through outreach and education campaigns can improve uptake of public health messaging without stigmatizing these species, while simultaneously promoting conservation. For example, a U.S. National Park Service study showed that educating the public about benefits of bats promoted the uptake of public health messaging and implementation of rabies risk reduction behaviors (Lu et al., 2016). With its reach across three continents, MENTOR-Bat could strengthen this positive awareness and maximize co-benefits on a larger scale. Similarly, following the COVID-19 pandemic a study found that public health messaging that prioritized educating citizens and enhancing general appreciation of biodiversity improved bat-related attitudes and beliefs. MENTOR-Bat aims to help reframe and mobilize conservation efforts as a pandemic prevention strategy and as a method to improve public health, education, and ecosystem function.

As a multi-country conservation fellowship program, MENTOR-Bat is uniquely positioned to develop a team of conservation and One Health champions who can foster the development of long-term, multisectoral frameworks for enhancing public education and awareness around bat conservation and zoonotic disease spillover risks. It also gives fellows an opportunity to take their training and background and apply it in new areas with transdisciplinary teams. Ultimately, this can enhance multisectoral capacity while normalizing transdisciplinary work around One Health challenges at the conservation-health-development interface. MENTOR-Bat aims to serve as a programmatic template for additional programs and information sharing networks to continue building long-term, sustainable One Health capacity for bat conservation and zoonotic spillover risk reduction.

Data availability statement

The original contributions presented in the study are included in the article. Further inquiries can be directed to the corresponding author.

Author contributions

LS: Writing – original draft, Writing – review & editing. NG: Writing – original draft, Writing – review & editing. MO'M: Writing – original draft, Writing – review & editing. WF: Writing – original draft, Writing – review & editing. ER: Writing – original draft, Writing – review & editing. KC: Writing – original draft, Writing – review & editing. AG: Writing – original draft, Writing – review & editing. JC: Writing – original draft, Writing – review & editing. JR: Writing – original draft, Writing – review & editing. LW: Writing – original draft, Writing – review & editing.

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Conflict of interest

Author LS was employed by AAAS Fellowship Programs, Inc.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer JRO declared a past co-authorship with the author WFF to the handling editor.

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Love Them & Leave Them: science-based rationale for a campaign at the public health-conservation interface

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Wild animals have been implicated as the source for disease outbreaks in humans (e.g., bubonic plague, Ebola, Hendra virus). Public health messaging intended to mitigate these zoonotic disease risks can inadvertently induce fear of wildlife, thereby resulting in wildlife culling and habitat destruction. We propose a science-based social marketing campaign – Love Them & Leave Them – to protect people and wildlife. This One Health campaign will be primarily implemented by public health communicators who work with government officials and/or local communities. The campaign's six key messages emphasize the inter-linkages between wildlife and human well-being for pandemic prevention and encourage the campaign target audiences to appreciate (love) wildlife while refraining from touching wildlife or occupying places that wildlife inhabit or feed (leave them … alone). We provide guidance for tailoring the global campaign vision to local ecological and socio-cultural contexts. The campaign is responsive to a recent call by multilateral bodies for governments to prevent pandemics at the source.

KEYWORDS
biophilia, communication, human health, social marketing, zoonoses

1 Introduction

1.1 Protect people. Protect wildlife

In this Perspective we draw on social science investigations to make the case for and propose a transdisciplinary social marketing (behavior change) campaign that prevents pandemics at the source—protecting people and protecting wildlife. The human species has evolved in concert with countless micro-organisms (microbes), some of which are highly beneficial for maintaining human health and others that have adverse, potentially fatal, health consequences (Rook et al., 2017). Peoples around the world have long recognized non-human animals as a source of disease-causing microbes transmissible to humans (zoonotic pathogens). Although the total number of zoonotic pathogens is undeterminable, at least 62% of the pathogens known to cause disease in humans have animal origins (Taylor et al., 2001) and at least 75% of emerging infectious diseases in humans are zoonotic in origin (zoonoses; Jones et al., 2008). Wild animals (wildlife) are implicated in the biological dynamics of most zoonoses and serve as major hosts (reservoirs) for zoonotic pathogen transmission. In this context, reservoir refers to the body of an animal in which an infectious microbe lives, multiples, and is viable for transmission to another host (CDC (CENTERS FOR DISEASE CONTROL AND PREVENTION, ND). For example, rabbits can carry *Francisella tularensis* which causes Tularemia, parrots can carry *Chlamydia psittaci* which causes Psittacosis, and various reptiles can carry various strains of *Salmonella* that cause Salmonellosis. Zoonotic disease risk mitigation may be at the root of cultural taboos that prohibit eating or otherwise encountering wildlife species believed to host pathogens of concern (e.g., Golden and Comaroff, 2015). Wildlife culling and habitat destruction are extreme, often fear-based, zoonoses risk mitigation measures that can have adverse impacts on wildlife populations. Research indicates that the process of enacting such measures may actually increase the risk of human exposure to zoonotic pathogens (Anderson and Reaser, 2024; this Research Topic).

Due to increases in human population size, economic growth, and the consequent impacts on ecological and climatic systems, the emergence and spread of zoonotic diseases is on the rise (Marie and Gordon, 2023). As a result, there is a growing perception that wildlife reservoirs constitute a major public health problem globally (Hilderink and De Winter, 2021). This perception and the responses to it—from local to multi-national levels—raise concerns for wildlife welfare and biodiversity conservation. Given the massive scale of wildlife extinction (Finn et al., 2023), it is imperative that public health messaging aimed at zoonoses risk mitigation aspires to hold two goals simultaneously: a) safeguard human health and b) protect native wildlife and the ecological systems they inhabit. In concept, a One Health approach to risk communication – one that considers human, animal, and environmental health (Pitt and Gunn, 2024) – could achieve messaging that motivates people away from wildlife-oriented behaviors that are risky for zoonotic pathogen exposure while simultaneously motivating people to appreciate and respect wildlife species of zoonotic concern. Kirkey (2024; this Research Topic) provides a Perspective on the importance of promoting biophilia (nature affinity) at the human health-biodiversity conservation interface.

1.2 A social marketing approach

Social marketing is the application of marketing principles and techniques to influence human behavior for a broad social good. It is a socially aware behavior change strategy that integrates behavioral science, psychology, and communication to promote actions that influence society as a whole (Andreasen, 1994; Ryan et al., 2019). Social marketing campaigns have been used in the conservation sector to influence behaviors beneficial to biodiversity conservation (Smith et al., 2020). These campaigns facilitate behavioral change, community engagement, awareness and education, cultural sensitivity, and the promotion of policy adoption and regulatory enforcement (Wright et al., 2015; Green et al., 2019). However, zoonoses risk communication typically falls under the purview of the public health sector, where messaging tends to prioritize human health and often overlooks the critical role of biodiversity in maintaining human well-being. The public health sector has a well-established history of employing social marketing to discourage at-risk behaviors and encourage healthy practices across various public health issues, including some infectious diseases (Grier and Bryant, 2005). Nevertheless, in the case of emerging zoonotic diseases, the focus remains predominantly on risk communication during zoonoses outbreaks rather than disease prevention. In the zoonoses context, public health communication often emphasizes urgency, immediate actions, and compliance, relying on straightforward and sometimes fear-based messaging (Decker et al., 2010; Tabbaa, 2010). Across conservation and public health sectors, there is a clear need for social marketing initiatives aimed at zoonotic disease risk prevention and mitigation that address the underlying motivation and barriers to fostering long-term behavior changes.

A transdisciplinary One Health social marketing campaign could dynamically and interactively motivate people to mitigate zoonotic disease risk by engaging in behaviors consistent with an appreciation and respect for wildlife. The application of social marketing to a wide range of wildlife-related behaviors allows for an understanding of the underlying motivations, beliefs, and social norms that shape human-wildlife interactions (Reddy et al., 2017). Campaigns can be tailored for different populations to reshape attitudes, challenge norms, and encourage behaviors that reduce the likelihood of exposure to zoonotic pathogens (Leonard, 2008). Drawing from different behavioral change theories, social marketing can identify barriers and facilitators to adopting zoonotic risk mitigation behaviors that can simultaneously foster a deep connection with nature (Glanz and Bishop, 2010). At the same time, social marketing can cultivate biophilia by promoting eco-centric values that underscore the interdependent, intrinsic bond between humans and wildlife, employing public health messages that resonate emotionally and cognitively with people's values (Ives et al., 2018). Through this integrated approach, social marketing provides a robust framework to align human behavior with public health objectives and biodiversity conservation, fostering a more harmonious and resilient coexistence between humans, wildlife, and their shared environment.

We recognize that social marketing campaigns aimed at behavior change are one aspect of a comprehensive zoonoses risk mitigation "toolkit" that may include additional approaches to risk communication, as well as veterinary, medical, or ecological countermeasures. In many instances, there will also to be a need to address social, cultural, and/or economic factors in order to reduce human exposure to zoonotic pathogens (e.g., by providing alternative livelihoods/food sources; WOAH (World Organization for Animal Health), 2024). We thus encourage a strategic approach to integrating the campaign into the matrix of risk mitigation activities, ideally such that they are mutually reinforcing and thereby enhance returns on investment.

2 Campaign framework

Love them and leave them. This is the essence of the message needed to promote biophilia while responsibly communicating wildlife-associated zoonoses risks with the aim of preventing zoonotic spillover (pathogen transmission to people). It is also the title of the global social marketing campaign that we propose herein. The Love Them & Leave Them campaign will promote two tiers of human behavior change:

1. Motivate human and animal health practitioners who engage in zoonoses risk communication to recognize the linkages between biodiversity conservation and health security and thereafter identify as One Health practitioners who will incorporate the campaign messages into their zoonoses risk communication programming.

   In general, these health practitioners will thus be motivated *away from* a single disciplinary/sectoral approach to risk communication *toward* an integrated One Health approach to risk communication that fosters human, animal, and ecological health simultaneously. Specifically, these practitioner's will be motivated to implement the Love Them & Leave Them campaign by implementing the second tier of behavior change – tailoring the campaigns to their context.
2. Motivate the human and animal health practitioner's target audiences for zoonoses risk communication to have an affinity for biodiversity, understand the role of wildlife in zoonoses disease transmission, and engage in behaviors that demonstrate an appreciation and respect for wildlife (even species believed to host zoonotic pathogens) while simultaneously taking precautions to avoid zoonotic pathogen exposure.

This audience will thus be motivated *away from* biophobia-induced actions against wildlife and wildlife habitats *toward* a biophilic relationship with ecological systems that ultimately reduces zoonotic disease risk by fostering landscape immunity– the ecological conditions that, in combination, maintain and strengthen the immune function of wild species within a particular ecosystem and prevent elevated pathogen prevalence and pathogen shedding into the environment (Reaser et al., 2022).

The Love Them & Leave Them campaign draws from the social sciences (e.g., communication psychology, neuro-linguistics, and social marketing frameworks), as well as the authors' first hand experiences in executing effective social marketing campaigns in the health and conservation sectors. We anticipate that campaign implementors will incorporate their own professional expertise, as well as geographic, cultural, and target species knowledge when contextualizing the campaign. It may be useful, for example, to consider how people vary in their perception of zoonoses risk due to differences in levels of trust and confidence in information (Sjöberg, 2000; Siegrist et al., 2005).

The overarching strategic framework for Love Them & Leave Them campaign development and launch is outlined in Table 1. Further refinement of the global campaign strategy will take place through a consultative process engaging the membership of at least two key campaign partners: IUCN (esp. the Commission on Education and Communication) and the International Alliance Against Health Risk in the Wildlife Trade (esp. the Human Dimensions Working Group).

The "love them" aspect of the campaign is intended to encourage an affinity for wildlife species even though the species can carry zoonotic pathogens (biophilic response). The campaign is primarily intended to influence people who might otherwise fear or disdain these species (biophobic response), particularly in contexts where the "dark emotions" elicited by their beliefs about species might result in wildlife culling and/or habitat destruction. Research has shown that love (related to compassion, connection, empathy, and attachment) is neurologically and molecularly linked to emotional self-regulation mechanisms (Esch and Stefano, 2011), meaning that people in states of love (biophilia) have a greater capacity to process information and make well-informed decisions about their actions than people in reactionary states of fear or disdain (biophobia).

The "leave them" aspect of the campaign addresses one of the key elements of zoonoses risk mitigation: the dynamics of proximity. The risk of being exposed to viable zoonotic pathogens is a function of contact (proximity) to infected wildlife, including the parts, excrement, bodily fluids, and products thereof (Reaser et al., 2022). Thus, refraining from direct or indirect contact with wildlife reservoir species and their habitats reduces the likelihood of zoonoses spillover (human infection). Generally, "leaving them alone" is thus optimal for human and animal health. There will, however, be important reasons for the campaign to recognize exceptions to the "leave them" aspect of the campaign message. Local and traditional peoples may have long-established relationships with some of potential pathogen hosts that result in close contact, even consumption. Where sustainable use of potential pathogen hosts takes place, the campaign messaging will need to be particularly socio-culturally sensitive (see further details in the next section). Public health officials and conservation practitioners may also have a need to come into close proximity with potential pathogen hosts to advance science and risk management. In such situations, the campaign message can be reinforced using non-contact approaches (as feasible), as well as the readily apparent use of personal protective equipment (PPE) to demonstrate contact minimization.

Six key messages have been developed for the global campaign:

- Protect people. Protect wildlife.
- Wildlife is important for human survival and well-being. Various species seed the forests, pollinate food crops and eat crop pests, and bring beauty and joy through their presence.
- Wildlife can also spread diseases to people, including some dangerous illnesses.

TABLE 1 Questions and responses that define elements of a strategic framework for conceptualizing, developing, and launching a social marketing campaign to foster appreciation (biophilia) and healthy respect for wildlife that have the potential to transmit zoonotic pathogens.

Strategic Planning Framework for the Love Them & Leave Them Campaign	
Questions to Address	Response
1. What are the final behavior changes that we want? (outcome) Problem behavior: Wildlife is killed and/or wildlife habitats are destroyed when the zoonotic disease risks associated with wildlife host species have been communicated via public health messaging in a manner that induces fear or other adverse emotions (biophobia).	• Target audiences are engaging in context-relevant actions to simultaneously: a) protect wildlife that can serve as zoonoses hosts (including protecting their habitats) [Love Them] & b) minimize the risk of zoonoses transmission from these wildlife species to people [Leave Them].
2. How will you know when you have achieved the outcome? (evidence)	• The target audiences will measurably understand the value of protecting the "wildlife host species" (Knowledge), demonstrate an affinity for the wildlife host species and express a desire to protect the wildlife species and their habitats (Attitudes), and take actions consist with this desire as a cultural norm (Behaviors). • The target audiences will *also* measurably demonstrate knowledge of zoonotic disease risks and risk mitigation opportunities associated with the host wildlife species (Knowledge), express a desire to protect themselves and others from these risks (Attitudes), and enact the appropriate risk mitigation measures (e.g., avoiding direct contact with the wildlife species) as a cultural norm (Behaviors).
3. Where, when, and with whom do you need to work? (context)	Where (Priorities) • Localities with a history of human-wildlife conflict involving wildlife host species. • Localities with a high risk of zoonoses emergence and/or spillover. When • Proactively to prevent human-wildlife conflict and zoonoses transmission. • As a rapid response measure when/where zoonotic outbreaks occur. With whom (Priority audiences) • Public health and animal health practitioners, especially those engaged in zoonoses risk communication. (Tier 1) • Community members most likely to influence other members' knowledge, attitudes, and behaviors. (Tier 2) • Government agency officials most likely to direct wildlife culls and/or destruction of wildlife habitats as zoonoses risk mitigation measures. (Tier 2)
4. How will achieving the outcome affect other relevant activities/initiatives? (impact)	Relative to goals: • Wildlife host species and their habitats will be protected, thereby supporting ecosystems more broadly and fostering socio-cultural and livelihood benefits. • Zoonoses spillover will be prevented, potentially preventing epidemics and pandemics. Broader positive consequences: • A One Health approach will be actualized at local to international levels. • Zoonoses risk can be better mitigated for wildlife used by local and traditional people in a sustainable manner. Potential perverse consequences: • In situations in which people harvest wildlife to meet local sustenance needs, "leaving wildlife alone" may not be an option and thus messaging could create a socio-cultural conflict. Context-specific nuance will be needed. • An expressed desire to protect wildlife host species may motivate some people to "polarity respond" – to persecute wildlife instead (e.g., to challenge perceived authority).
5. What stops you from having the outcome already? (barriers)	• Although a One Health approach has been widely conceptualized, it is not yet well-practiced. • Public health messaging does not typically consider conservation or animal welfare goals. • Conservation messaging does not typically consider public health goals. • Funding for further campaign development and implementation.
6. What resources do you already have that will contribute to achieving the outcome? (existing resources)	• General public awareness of pandemic consequences due to COVID-19 outbreak. • Prior experience designing and implementing effective social marketing campaigns. • Thematic networks for campaign development and distribution (e.g., IUCN Commission for Education and Communication, International Alliance Against Health Risks in the Wildlife Trade). • Collection of relevant papers in this Research Topic. • Campaign brand and brand messaging (flexible for tailoring according to language/context needs).
7. What additional resources do you need to achieve the outcome? (resource needs)	• Consultation with key networks for campaign development. • Campaign implementation toolkit. • Campaign website to host brand materials, implementation toolkit, and local campaign spotlights, including lessons learned. • Campaign launch event and ongoing campaign promotion to target audiences. • Training programs in campaign tailoring and implementation. • Financial resources to support the above.
8. How are you going to achieve the outcome? (initial steps)	• Publish campaign proposal/framework (This Perspective). • Conduct campaign consultations with experts in relevant thematic networks to further develop the campaign brand and messaging.

(Continued)

TABLE 1 Continued

Strategic Planning Framework for the Love Them & Leave Them Campaign	
Questions to Address	Response
	• Raise necessary funds and develop campaign materials and platforms. • Provide seed grants to support initial local campaigns. • Globally launch the campaign at the 2025 World Conservation Congress and 2026 World One Health Congress in partnership with the International Alliance Against Health Risks in the Wildlife Trade and IUCN (among others).

- The risk of getting a disease from wildlife increases if you touch wildlife or occupy places that wildlife frequent (e.g., caves that bats live in or trees where they feed).
- Love wildlife! Wildlife makes life better. Healthy wildlife equals healthy, happy people.
- Leave wildlife alone! Be safe and kind. Avoid handling wildlife (dead or alive) or occupying places that wildlife inhabit or feed. Harming wildlife may be a crime.

The campaign brand (Figure 1A) clearly states the two campaign goals: 1) protect people and 2) protect wildlife (particularly species that may host zoonotic pathogens). The protection of people is stated first because the campaign will be primarily implemented through the public health community. The two behaviors the campaign is intended to elicit are also explicitly stated in the logo. The "Love Them" statement is in red type as red is commonly associated with love and romance. It is stated in the largest font in the logo to invoke a sense of association with the message. The "Leave Them" statement is in smaller, dark gray text to invoke a sense of disassociation and distance that is consistent with the message. The ampersand emphasizes that the behaviors are to be enacted in concert rather than as options. Size, distance, color, and location are all submodalities (codings) of the visual representational system that influence one's sense of experience and behavioral responses to that experience. The distinction of form or structure has deeply held (subconscious) associations with

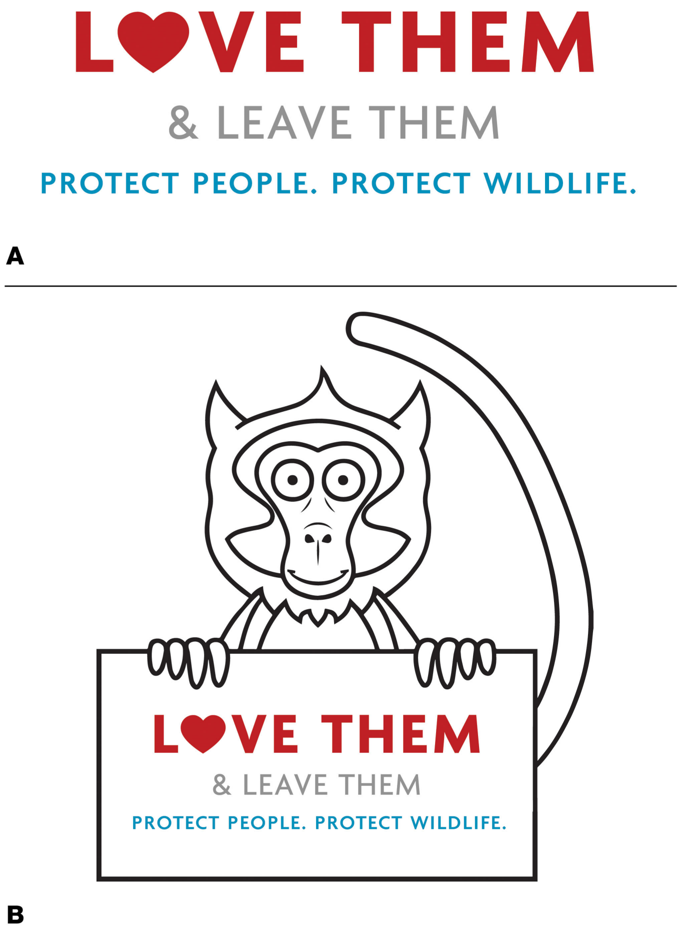

FIGURE 1
Brand concepts for the Love Them & Leave Them campaign depicting the succinct global campaign tagline message **(A)** and a means of localizing this message by pairing it with illustrations of wildlife species of particular concern **(B)**.

individual and collective values and beliefs–and can therefore motivate human behavior more strongly and lastingly than content stimuli (Zamfir, 2014; Grosu et al., 2021).

The global campaign is intended to be sufficiently flexible to allow for the fit-to-context modifications necessary for campaign effectiveness, including presentation in different languages and with different wildlife species. Note that the verbiage in the campaign brand (Figure 1) and primary messages is short and jargon-free, thereby enabling translation that is clear, concise, and accurate. The primary messages can be contextualized by replacing the word "wildlife" with the name of specific wildlife species and phrases such as "Harming wildlife might be a crime" can be replaced by a statement about locality-specific regulations. The brand image can be displayed as text only (Figure 1A) or as signage held by an illustrated version of one or more wildlife species that are the contextual focus for zoonoses risk mitigation (Figure 1B). Culturally relevant symbols, organizational logos, and other art that contextualizes the campaign can be incorporated into illustrated presentations of the brand image. Further guidance for localizing the campaign is provided in Section 3.

We anticipate that Love Them & Leave Them campaign implementation will vary with context. We intend to create a set of clear, concise, adaptable materials that are readily accessible on a digital platform. To explain the need for the campaign and its behavior change goals, subject matter papers and briefing notes will accompany the campaign materials. We will also provide a compendium of general guidance on the design and implementation of social marketing (behavior change) campaigns, as well as standards for Love Them & Leave Them campaign messaging and brand application. The site will provide contact information for campaign mentors.

3 Guidance for localizing the campaign

The success of the Love Them & Leave Them campaign is contingent upon its effective localization, given the variety of human-wildlife interactions across a spectrum of cultural, ecological, and socioeconomic contexts. The following brief guidance for localizing the campaign focuses on assessment and planning to further clarify and expand the campaign framework, ensuring that the core message remains impactful while respecting local realities. This guidance is drawn from the work on the IUCN Commission on Education and Communication (Oepen and Southey, 2024).

3.1 Audience and one health stakeholder analysis

The campaign is developed to primarily target human and animal health practitioners engaged in zoonotic risk communication and their audience. Further context-based analysis should be conducted to identify local audiences who will be potentially influenced by zoonotic risk communications based on various interactions with wildlife (e.g., local communities living nearby natural habitats, Indigenous groups, park managers or rangers, etc.) and/or who may be involved in biophobia-induced behaviors. A comprehension of the audience's demographic, social, and economic background will also help determine the most accessible and preferred communication channels for the campaign (Noar, 2006).

Involving a diverse range of stakeholders from multiple disciplines and sectors is critical for the development and implementation of the campaign (The World Bank, 2018). Identifying a wide range of local One Health stakeholders will ensure the inclusion of key decision-makers for zoonotic disease risk mitigation. It is imperative to include who might direct wildlife culls or habitat destruction, whether representatives of human or animal health agencies or members of community groups. Forming partnerships with media outlets, journalism organizations, and education institutions is potentially beneficial in identifying suitable communication channels and broadening the campaign's impacts. Collaboration with industry partners (e.g., eco-tourism, agriculture corporations, etc.) and government and international organizations interested in a One Health approach may help mobilize resources for the campaign.

3.2 Species-specific design

While the overall campaign may focus on various wildlife species, featuring species of local concern as potential zoonotic reservoirs should be prioritized. The campaign brand materials can be designed with tailored imagery and messages to ensure accurate and recognizable depictions. Assessments of local taboos, spiritual beliefs, cultural significance, and practices associated with specific wildlife species can enable incorporation of culturally appropriate imagery, language, and messaging so as to increase campaign comprehension and the acceptability (Voyer et al., 2015). In instances where cultural beliefs, traditional practices, and social norms significantly influence how risks are perceived and managed, co-creation with partners within local communities may be a valuable approach (Waylen et al., 2010; Asaaga et al., 2022). Multi-dimensional information about the ecological roles, cultural significance, and associated zoonotic risks of wildlife species will lay a knowledge foundation to foster attitude and behavior changes (Schrader and Lawless, 2004). If applicable, aligning the campaign message with local wildlife protection regulations may help shape human behaviors and reinforce the campaign's legitimacy. These activities will also strengthen the multi-sectoral platform by facilitating the coordinative, responsive, and adaptive campaign design, implementation, and evaluation.

3.3 Social and economic considerations

Although "Leave Them" is the optimal option for human and animal health, it is crucial to acknowledge the potential conflicts between campaign objectives and local livelihoods and traditional practices dependent on wildlife use or trade, where completely avoiding wildlife contact is not a viable option. It is recommended that nuanced messaging be developed in collaboration with community leaders and traditional knowledge holders to respect customary use while promoting safe practices (van Vliet et al., 2018; Kadykalo et al., 2021). It may be beneficial to offer practical and context-based alternatives that emphasize risk mitigation strategies (e.g., proper handling and hygiene practices) rather than complete avoidance. Additionally, framing messages around the concept of healthy wildlife populations ("Love Them") could be a viable approach for promoting sustainable traditional practices.

3.4 Monitoring and evaluation mechanisms

Monitoring and evaluation are essential parts of this campaign. Table 1 provides some recommended indicators for evaluating the campaign, more measurable indicators can be developed based on the specific messages, communication channels, and audience. In contexts where resources are limited, it is possible to implement practical monitoring and evaluation mechanisms by leveraging existing data from knowledge, attitude, practice studies, and health and conservation data systems to establish baseline metrics and measure the impact. Using digital tools and stakeholder feedback and review mechanisms may lower costs in data collection and improve real-time analysis. As a global campaign, establishing a mechanism for sharing lessons learned across the various localized implementations will benefit a broad range of implementers. WOAH (World Organization for Animal Health) (2024) provides guidance for monitoring and evaluation in the context of zoonoses risk mitigation.

4 A call to action

In 2023, the Quadripartite, consisting of the Food and Agriculture Organization of the United Nations (FAO), United Nations Environment Program (UNEP), World Health Organization (WHO) and World Organization for Animal Health (WOAH), came together to urge all countries and key stakeholders to, among other things, "strengthen and sustain prevention of pandemics and health threats at source, targeting activities and places that increase the risk of zoonotic spillover between animals to humans" (World Health Organization, 2023). Members of the One Health High-Level Expert Panel (OHHLEP) have reiterated this zoonoses risk mitigation priority (One Health High-Level Expert Panel et al., 2023). The Love Them & Leave Them campaign provides an opportunity for donors, national governments, and multi-lateral frameworks to respond to these calls to action. Further, the campaign provides an opportunity for those working in the public health and conservation communities to collaboratively actualize the One Health approach from global to local scales of impact. To prevent future pandemics, we must learn to love this world and act responsibly toward each other.

Author contributions

JR: Conceptualization, Funding acquisition, Project administration, Resources, Visualization, Writing – original draft, Writing – review & editing. HL: Resources, Writing – original draft, Writing – review & editing. SS: Conceptualization, Resources, Writing – original draft.

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Art can provide a means for promoting biophilia as an aspect of zoonoses risk communication

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The COVID-19 pandemic served as a call to action for scientists to find new and creative ways to prevent future pandemics. Because value-based emotions underly human behavior, scientific facts alone have proven to be a poor motivator to change the behaviors that increase zoonotic spillover risk. Emotions can translate in psychological stances such as biophobia, the fear of or aversion to nature, and biophilia, the appreciation of nature. Educating the public about species that may pose a zoonotic risk can have the unintended effect of inducing biophobia into the public psyche. This can lead to increased zoonoses risk. In this Perspective, I make the case that strategically employing art can be an effective method to communicate zoonotic risk while promoting biophilia. Using art as a method of communication has been explored by various scientific fields but has not been sufficiently applied to infectious disease messaging.

KEYWORDS

zoonoses, biophilia, biophobia, art, communication, education, nature

1 Introduction

Land use change and other ecological impacts can drive the emergence and spread of zoonotic pathogens—disease-causing microbes transmitted between non-human animals and people. Deforestation and urbanization can also lead to increased rates of interaction between wildlife that hosts zoonotic pathogens and humans, allowing for an increased rate of spillover (transmission) events. Therefore, zoonotic disease mitigation is an environmental issue and nature-oriented solutions are needed to mitigate zoonoses risk (Reaser et al., 2022).

If spillover events are caused by increased instances of interaction between humans and the wildlife, shouldn't public health messaging be focused on distancing people from the natural world? No. A disconnection from nature can intensify the factors driving spillover events. For example, when people fear wildlife species that have the potential to transmit zoonotic pathogens, they may kill (cull) these species and/or destroy their habitats. This can increase pathogen exposure in the short-term (Anderson and Reaser, 2024) and further degrade ecosystems over the long-term. There is a need to educate people on how to appreciate nature safely—to promote biodiversity conservation while responsibly providing public health messaging.

During the COVID-19 pandemic caused by SARS-CoV-2, it became apparent that scientific data alone could not convince all people to engage in behaviors that would reduce their risk of contracting or transmitting the disease. Kwon et al. (2021) found that effective social distancing caused a 31% decrease in COVID transmission risk, and wearing a mask reduced COVID risk by 62%; yet Taylor and Asmundson (2021) found that, despite the science proving the effectiveness of masks in COVID prevention efforts, 10%-15% of American and Canadian adults did not wear masks in public. Several anti-mask rallies took place globally, participants often numbering in the thousands (Taylor and Asmundson, 2021). Gorman and Gorman (2021) conclude that people are often resistant to changing their minds based on fact alone and are more responsive to emotions than to statistics. They propose that scientists must find a way to bridge this communication gap by acknowledging the emotions that drive human behavior rather than relying on facts alone to generate behavior change. The challenge of responsibly communicating infectious disease risk while fostering biophilia is complicated and requires a creative solution. In this Perspective, I propose the use of art as an effective means of communicating environmental understanding to move people away from fear (biophobia) of wildlife that may host zoonotic pathogens toward feelings of appreciation and respect (biophilia), thereby promoting biodiversity conservation efforts and decreasing zoonoses risk. Positive, associative experiences with nature have been shown to increase feelings of human wellbeing, connectedness, and empathy, which in turn can lead to an increased appreciation for conservation efforts (Kirkey, 2024). Recognition that interactions with nature influence human emotions and thus human behavior informs development of a dual-purpose messaging strategy.

2 Biophobia

> "There are many animals, who though far from being large, are yet capable of raising ideas of the sublime, because they are considered as objects of terror. As serpents and poisonous animals of almost all kinds. And to things of great dimensions, if we annex and adventitious idea of terror, they become without comparison greater." (Burke, 1958)

Pathogen transmission from wildlife to humans is one of the main sources of emerging infectious diseases (Ellwanger and Chies, 2021). The frequency of these spillover events can be attributed to several factors, including increasing land use and the widespread wildlife trade. The lack of global education and awareness about the risks of coming into contact with wild animals is a major cause for public health concern (Vora et al., 2023) The solution may seem simple – educate the public about the risks associated with exposure to wildlife. However, public health messaging can unintentionally create a negative impact by generating feelings of biophobia towards different animal species associated with disease (Anderson and Reaser, 2024).

Soga et al. (2023) defines biophobia as, "the adverse response, such as fear and disgust, that people can show towards some natural stimuli, settings, or situations." Biophobia exists for a variety of reasons, ranging from pop culture horror to personal traumatic experiences. Some argue that biophobia is an innate reaction meant to keep oneself safe from the parts of nature that could be dangerous (Soga et al., 2023). Sentiments of fear, disgust, and other aspects of aversion cause people to use chemical repellents, glue traps, or poison to protect themselves from animals viewed as disease-carrying pests. Typically, these pest-control methods kill the target species in inhumane ways and may have adverse consequences for non-target species as well (Mason and Littin, 2003). Thus, biophobic responses to wildlife disease risk can harm wildlife populations and impact delicate ecological systems (Soga et al., 2023). It is true that wildlife can carry zoonoses. It is also true that animals associated with zoonoses play important roles in keeping their ecosystems healthy by stimulating plant growth, spreading seeds to promote biodiversity, and acting as a source of food for other animals (Sieg, 1987). However, once an animal is associated with disease it can be challenging to refocus the narrative on the ecological importance of these species (Soga et al., 2023).

3 Biophilia

> "Humanity is exalted not because we are so far above other living creatures, but because knowing them well elevates the very concept of life. Splendor awaits in minute proportions." (Wilson, 1984)

Vora et al. (2023) point out that humanity's broken relationship with nature heightens pandemic risk. Promoting biophilia could be the answer to mending this rift. Wilson (1984) defines biophilia as "the innate tendency to focus on life and lifelike processes." Humans have a natural curiosity about the world and fostering that sense of curiosity instead of allowing fear to rule perceptions of nature is necessary to transmute biophobic patterns (Soga et al., 2023). Kirkey (2024) proposes that fostering biophilia can promote conservation efforts while mitigating spillover risk. The question is: How? Feelings of biophobia can be deeply ingrained in the public psyche and thus pose a challenge to promulgating feelings of biophilia.

4 Art

For the purposes of this Perspective, art is inclusive of both visual and performing arts. In an examination of the emotional responses tied to art, Ducasse (1964) observes that "art is the language of the emotions" and therefore has the ability to communicate the feelings of the artist to the audience. Art induces emotional reactions at multiple levels of the psyche. Basic emotions are those related to our survival such as fear, joy, disgust, sadness, and anger (Collet et al., 1997). These emotions drive biophobic and biophilic responses. The emotions evoked by art are called “aesthetic” emotions (Tan, 2000). Aesthetic emotions may stem from basic emotions, but they tend to be more specific and nuanced. Some examples of aesthetic emotions include pleasure, awe, and wonder (Schubert, 2024). Tan (2000) examined the relationship between aesthetic and basic emotions and found that aesthetic and basic emotions work together to form opinions of art works. When an individual views art, they are aware that the art is a representation of a theme, and therefore can appreciate it from an objective and aesthetic perspective. However, if the theme in the art sparks a memory in the individual, this will evoke an empathetic and emotional response, allowing them to connect to the art piece on a deeper level. Nummenmaa and Hari (2023) observed that visual art can induce a physical response in its audience, such as facial movements or clenched fists, in the same way as basic emotions.

Throughout human history, lessons and other information have been communicated to society using various artistic methods such as paintings, sculptures, and stories (Carroll, 2004). Art as means of communicating ideas has been extensively explored in a variety of scientific fields. The World Health Organization reviewed 900 publications reporting on nearly 4000 studies focused on the benefits of using art to improve health and found conclusive evidence that there is a positive correlation between the two—art benefits human health (Fancourt and Finn, 2019). Thomson et al. (2020) evaluated the biopsychosocial effects of using art and nature to improve mental health and found that, along with improved wellbeing, the arts were an effective way to communicate messages and encourage positive behavior change to the participants.

Interactive, art-based education has proven to be an effective tool for raising awareness about endangered species conservation. Boonchutima et al.’s (2022) study evaluated memory retention of participants interacting with an artistic exhibit focused on Thai elephant conservation. Participants who perceived the experience as interactive noted an increase in their awareness of Thai elephant conservation efforts. Upon follow-up a year and a half later, participants were able to share remembered details about the exhibit and facts about elephant conservation practices. Art-based education has also been used to raise awareness about the conservation of less charismatic species. An art exhibit focused on the Salt Creek tiger beetle (*Cicindela nevadica lincolniana*) compiled a diverse collection of pieces from local artists interested in beetle conservation. Of the exhibit’s attendees, 13% were surveyed. The most significant change in perceptions of the Salt Creek tiger beetle was observed in adult non-academics who had little to no prior knowledge of the insect. Some recorded responses from these individuals indicated that the exhibit had evoked an emotional response and their knowledge on Salt Creek tiger beetle conservation had increased. Overall, there was shown to be an increase in recognition of the importance of insects in an ecosystem (Brosius et al., 2014).

The application of art at the biodiversity conservation-zoonoses prevention interface is not yet well established. However, the travel exhibit, *ZOONOSES*, which examines human perceptions of zoonoses and zoonotic hosts, provides a useful model (Hooper and Reeves, 2022). The goal of *ZOONOSES* is to raise awareness about zoonotic pathogens and their hosts through an interactive, fairy-tale inspired exhibit. Hooper recognizes that there are many animals that are negatively perceived because of their association with disease and strived to create an educational space where viewers “end up being less fearful and also have a more balanced perspective of nature” (Devonport Regional Gallery, 2023). Along with providing education through the art itself, Hooper assisted in the creation of an educational resource to be reviewed and completed while viewing the *ZOONOSES* exhibit. This educational resource challenged the audience to contextualize the exhibit by asking what roles humans and animals play in the spread of zoonoses (Hooper and Reeves, 2022).

5 Conclusion

Promoting biophilia is essential in maintaining public respect for wildlife while also providing education about zoonotic disease risk. On their own, neither fact nor emotion are strong enough to influence the type of behavior change needed to prevent zoonotic spillover. There is merit in exploring art as a pathway to pandemic prevention and biodiversity conservation. Allowing an audience to interact with art is a way to generate feelings of empathy and understanding towards subjects that may be uncomfortable to look at through a purely scientific lens. Interdisciplinary approaches allow for various interpretations to help resolve conflicts in creative ways. It is time to eliminate the divide between the fields of art, science, and healthcare and unite under the shared motivation to put an end to the pandemics that impact us all. There is a need for a social marketing campaign that engages the public health and conservation communities in the practice of using art to communicate zoonoses risk mitigation and biodiversity conservation messaging in concert.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

PB: Writing – original draft, Writing – review & editing.

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Responsible biophilia for zoonosis prevention through a cultural lens

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Human affinity for nature ("biophilia") brings substantial health and ecological benefits and fosters environmental stewardship. However, close human-nature interactions can lead to conservation challenges and increase the risk of zoonoses. This paradox raises critical questions about how to balance public health, biodiversity conservation, and sustainable development, and understanding these dilemmas presents opportunities for integrated approaches seeking synergies rather than trade-offs. This perspective explores the complexities of these intricate challenges by examining cases that demonstrated the interconnections between biophilia and zoonotic risks and their implications for conservation, public health, and local livelihood. Acknowledging the role of social and cultural perspectives in shaping human-nature interactions, this perspective highlights the importance of integrating traditional knowledge and practices and tailored risk communications into community-centered initiatives for zoonotic risk mitigation. The discussion proposes a responsible biophilia approach that embraces biodiversity conservation as a primary strategy for zoonosis prevention. By fostering responsible biophilia through a transdisciplinary and culturally relevant approach, we can align conservation, public health, and sustainable local livelihood, transforming biophilia-based human-nature interaction into opportunities for community health and resilience.

KEYWORDS

biodiversity conservation, biophilia, traditional knowledge and practices, integrated approach, zoonoses

1 Introduction

The inherent affinity to nature in humans ("biophilia") is shown in diverse ways in which we seek to interact with various life forms in our shared environment (Kellert and Wilson, 1995). Through the course of evolution, humans have acquired knowledge and experience through interactions with nature, at the same time forming minds and behaviors that modify nature for the benefit of humans. The establishment of connections with nature offers substantial benefits to human health and fosters a sense of care and ethical obligation that generates environmental stewardship to maintain a healthy ecosystem (Heerwagen, 2009). However, biophilic activities often bring humans and nature into close interactions, raising health concerns for animals, humans, and ecosystems (Spanjol and Zucca, 2023). The intricate relationship between biophilia and zoonoses unveils a multifaceted landscape, presenting both challenges and opportunities to nurture sustainable human-nature relationships. This perspective delineates the challenges of balancing zoonosis prevention, conservation, and local livelihoods in human-nature interactions and discusses the role of socio-cultural factors in shaping human-nature interactions, influencing conservation and zoonosis prevention. Drawing from community practices, the perspective introduces the concept of responsible biophilia, which emphasizes ethical, sustainable, and health-conscious engagement with nature to maintain a healthy ecosystem that is essential for zoonosis prevention, conservation, and sustainable development. Grounded in the principles of One Health, the perspective outlines pathways to transforming human-nature interactions into opportunities for zoonosis prevention by integrating biodiversity conservation, community-driven initiatives, and culturally sensitive approaches.

2 Challenges to biophilia and zoonosis prevention

2.1 The paradox between biophilia and health

Many nature-based activities, or biophilic activities, offer substantial mental and physical benefits to humans, but certain activities are also potential causes for zoonoses that are transmitted between humans and animals or via natural environments (e.g., water and soil). A number of zoonoses are known to be associated with biophilic activities. These include the recent B virus human case in Hong Kong where the patient was injured (e.g., scratches or bites) by monkeys in a park (Verma et al., 2024); Lyme disease that is transmitted through tick bites during outdoor activities in North America (St. Pierre et al., 2020); and different water-borne zoonotic parasite infections contracted from swimming in open water (Nithiuthai et al., 2004). While green spaces such as parks and gardens are critical for urban ecosystems and communities, inadequate health and environmental management may result in the emergence of tick- and rat-borne diseases in humans and animals (de Cock et al., 2023; Smith et al., 2015).

Furthermore, the affection of animals has been driving the trade of various species for pets, facilitating the emergence and transmission of zoonoses during the translocation of live animals from their natural habitats to human-dense environments across regions and continents, regardless of the legality of these practices (Borsky et al., 2020; Pavlin et al., 2009). Meanwhile, pet ownership without proper veterinary care can lead to infections of different bacteria, fungi, parasites, and viruses in humans (Stull et al., 2015). Some pets (e.g., dogs) are also known as the intermediate host for disease transmission between humans and wild animals (Chomel, 2014). The health benefits of biophilic activities and the negative impacts of these activities on human and animal health, particularly in the context of zoonoses, raise questions about how to achieve the optimal health and well-being of humans, animals, and our shared environment in human-nature interactions.

2.2 The dilemmas of conservation, health, and local livelihood in zoonosis control and prevention

Many control measures for zoonoses involve culling or restricting wildlife movement, which often conflicts with conservation priorities and biophilic connection to nature. While these measures are intended to reduce disease transmission, they could cause unintended ecological, economic, and social consequences, which sometimes amply the risks they are designed to mitigate. For instance, mass culling of bats has been proposed as a response to outbreaks of rabies, Nipah virus, and Hendra virus in various countries. However, studies have shown that bat culling can disrupt colony structures and disperse infected individuals, potentially increasing the likelihood of disease spillover rather than preventing it (Anderson and Reaser, 2024; Miguel et al., 2020; Rocke et al., 2023; Viana et al., 2023). Additionally, bats play a vital role in pollination and insect control, and their population decline can lead to ecosystem destabilization and a decline in agricultural productivity (Kasso and Balakrishnan, 2013). In China, large-scale rodent control campaigns in the Inner Mongolia grasslands and Qinghai-Tibet Plateau for plague outbreak control and prevention have led to significant disruptions in the food chain. The extermination of Brandt's voles, considered a plague reservoir, has negatively impacted the populations of predators such as foxes, birds of prey, and weasels, leading to trophic cascades and further imbalances in rodent populations (Zhang et al., 2003). These interventions have not only been unsuccessful in eliminating disease risks but have resulted in broader ecological concerns.

Beyond the control of wildlife, zoonosis prevention measures by restricting human access to nature have the potential to impose hardship on local communities. The closure of wet markets and bans on wildlife trade, actions that have been implemented during the course of pandemics, resulted in economic losses and food insecurity for millions, particularly in developing regions, where local markets serve as primary sources of nutrition and livelihoods for local communities (Erokhin and Gao, 2020; Musa and Basir, 2021). In addition, the establishment of protected areas and conservation zones, aiming to minimize human-wildlife interactions, may unintentionally displace Indigenous and local communities, thereby restricting their access to critical resources such as food, medicinal plants, and culturally significant landscapes (Coad et al., 2008). Therefore, while implementing zoonosis control and prevention measures is imperative, their design and implementation must be equitable and just, considering the disproportionate impacts on vulnerable populations and socioeconomic factors, to not only protect nature and prevent diseases but also to promote the well-being of local communities.

3 Social and cultural dimensions of biophilia and zoonosis

3.1 Influence of social and cultural factors on human-nature interactions

Existing understanding of the various ways people interact with animals in local communities underscores the important role of social and cultural perspectives in shaping perceptions of disease risks and biophilia. Moreover, it reveals the significance of traditional and local knowledge in shaping views and perceptions about animals, thereby influencing human-nature relationships and interactions. For instance, communities and groups across diverse cultures and geographic regions describe animals as pets, pests, or food based on their knowledge and experience, resulting in varied patterns of human-animal interactions. In Asian and African countries, people from different cultures and ethnicities utilize various parts of pangolins for medicinal, food, and other religious and cultural purposes (Aisher, 2016; Boakye, 2018). Traditional medicine sourced from wild plants and animals remains an important healthcare resource for communities where access to conventional medicine is limited (Alves and Rosa, 2007). However, the belief in the medicinal function of some wildlife has been a driving force behind the sourcing and trade of animals and plants from the wild. These activities create opportunities for human-wildlife contact, which favors zoonosis emergence and transmission and results in the overexploitation of wild species.

Despite the conservation and health consequences associated with local practices, some culture-based practices can help reduce human-animal contact and potentially mitigate zoonotic risks. In many local and Indigenous communities, traditional knowledge is rooted in the profound connection to nature, characterized by beliefs in nature's offerings and the sanctity of the environment. This connection generates environmental stewardship, demonstrated by the reverence many cultures hold for specific species, considering them as totems or spiritual beings. This reverence plays a role in deterring interactions with these animals, contributing to conservation and zoonosis prevention (Landim et al., 2023). For instance, in Madagascar, Aye-Aye (a species of lemur) is regarded as sacred, and local communities adhere strictly to the taboo that helps limit hunting and consumption (Golden and Comaroff, 2015). While carnivores are often perceived as a threat to local livelihoods and agriculture, pastoral communities in South Asia and QinghaiTibetan Plateau China are found to be more tolerant of carnivores such as snow leopards and wolves, despite considerable livestock losses due to depredation. This can be attributed to the cultural perception of snow leopards as the guardian deity of the sacred mountains and the influence of Tibetan Buddhism (Kusi et al., 2020). These beliefs in sacred landscapes, groves, and animals in various cultural groups, often embedded in religions, represent the emotional, economic, and cultural attachment of human beings to nature (Kala, 2017). Similarly, Buddhist monasteries in Asia often function as sanctuaries for animals, protecting them from overexploitation (Dudley et al., 2009), which can potentially help mitigate zoonotic risks from hunting and consumption.

3.2 Leveraging local and traditional knowledge and practices in community initiatives

It is crucial to recognize and acknowledge the significance of local and traditional knowledge and practices in forming effective, ethical, and sustainable public health and conservation strategies that target human-wildlife interactions. The integration of traditional ecological knowledge into community-led conservation and sustainable resource management has yielded positive outcomes in some programs. For instance, in Ethiopia, the Oromo Gada system, an Indigenous institution, has managed natural resources and livestock in a way that prevents environmental degradation and reduces zoonosis transmission (Bedada, 2021). In Canada's Arctic, Inuit hunters have played a crucial role in tracking wildlife disease patterns, aiding in zoonosis monitoring and surveillance (Keatts et al., 2021). In West Africa, traditional healers incorporate plant-based treatments for zoonotic diseases like brucellosis and malaria in humans and parasites and infections in animals, reducing reliance on antibiotics and mitigating antimicrobial resistance (Gbenou et al., 2024; James et al., 2018). These examples underscore the potential of integrating and formalizing traditional knowledge and culture-based environmental stewardship to enhance zoonosis surveillance and prevention efforts and illustrate how such efforts can foster sustainable and culturally relevant practices in local communities through community participatory programs.

3.3 Developing culturally relevant communication strategies

Understanding and responding to local beliefs and cultures is vital for effective responses to disease outbreaks and zoonosis prevention, as well as fostering community trust to achieve further behavior change. In Bangladesh, despite the message from the health authority, the belief that the Nipah outbreak was caused by supernatural forces, instead of knowledge about bats as the source, hindered the protective measures taken by local communities to cease the consumption of contaminated palm sap by bats, causing Nipha virus transmission to humans (Parveen et al., 2016). During the Ebola epidemic in Sierra Leone, health officials collaborated with religious leaders to promote Ebola-safe burial practices that preserved cultural rituals while preventing disease spread. Religious leaders also served a critical role in community sensitization and communication of Ebola related information (Lee-Kwan et al., 2017). In Malaysia, scholars were integrating zoonotic risk awareness into the operation manual for halal slaughter to promote safe animal handling practices that can help prevent zoonoses (Min et al., 2018). Across the world, local religious leaders and groups have contributed to the preservation of ecosystems and the promotion of planetary health. These include reducing wildlife trade and consumption and protecting forests through community engagement and policy advocacy (Mcleod and Palmer, 2015). In Vietnam, women play a primary role in poultry care and trade but were initially excluded from disease prevention efforts (e.g., avian influenza). Engaging women in training as peer educators is contributing to improved poultry management and zoonotic risk mitigation (Mitchell, 2019). Across these diverse settings, successful zoonotic risk communication efforts have depended on the use of culturally relevant messaging and culturally familiar narratives in a participatory manner to build community trust, sustain behavior change, and achieve more effective intervention.

4 Resolving the paradox and dilemma with a biophilia-based approach to zoonosis prevention

4.1 Fostering responsible biophilia for safe and sustainable human-nature connection

Despite the potential zoonotic risks from close human-animal contact, when guided by responsible principles centered on biodiversity conservation and ethical interactions with nature, biophilia can help mitigate these risks by maintaining healthy ecosystems and promoting safe and sustainable human-nature interactions. Biodiversity plays a critical role in regulating pathogen transmission and controlling host populations to limit disease spillover (Plowright et al., 2024). Responsible land use to protect intact ecosystems can serve as a natural defense against zoonotic threats while supporting local livelihoods (Dobson et al., 2020). Sustainable use of wild resources, such as regulated hunting, non-timber forest products, and agroforestry, can provide economic benefits while minimizing habitat destruction and human-wildlife conflict (Fromentin et al., 2023). Ethical and sustainable ecotourism exemplifies how human-wildlife interactions can be managed to minimize health risks while promoting conservation and economic benefits. In Liberia, ecotourism sites have been designed to allow safe bat watching without disturbing natural roosting habitats and reducing the likelihood of zoonotic transmission (IUCN and EcoHealth Alliance, 2022).

Human settlements and land-use practices should be designed in a manner that fosters both ecological integrity and public health. Urban planning that integrates green spaces without increasing vector habitats can improve human well-being and reduce disease risk at the same time (Fournet et al., 2024). In the United States, wildlife-friendly urban planning has considered bat-friendly dwelling designs, allowing people to coexist with bats in ways that reduce zoonotic risks while maintaining their ecological role in pest control and pollination (Pfeiffer, 2019). In addition, educational initiatives on responsible pet ownership have the potential to mitigate zoonotic risks associated with the exotic pet trade. These examples highlight the potential of a responsible approach to land, animals, and natural resources stewardship, which can foster a sustainable human-nature connection while contributing to human health and economic development. By cultivating a sense of responsible biophilia, we can transform human-nature interactions into opportunities for disease prevention, ensuring that conservation, economic development, and public health reinforce one another mutually rather than competing.

4.2 Promoting biodiversity conservation as a zoonotic risk mitigation strategy

Biodiversity conservation serves as a natural defense against zoonosis emergence by maintaining healthy ecosystems that regulate pathogen transmission (Plowright et al., 2008). Several community-led conservation programs have demonstrated the potential for synergies between conservation, public health, and local needs, pointing to the possibility of mutually beneficial outcomes (Brooks et al., 2012). Payments for Ecosystem Services (PES) programs compensate communities for biodiversity conservation efforts, reducing habitat destruction while lowering human-wildlife conflict and interactions and potential zoonotic spillovers (Salzman et al., 2018). In the agricultural sector, wildlife-friendly farming through reduced intensity of agricultural management and integrated conservation actions has been shown to increase the richness and abundance of plants, bees, and bird species (Pywell et al., 2012). Wildlife-friendly livestock management with non-lethal predator management and changes in grazing strategies have helped promote mammalian biodiversity recovery, thereby supporting healthy ecosystems for livestock and maintaining the co-existence of zoonotic pathogens and reservoirs to mitigate spillover risks (Schurch et al., 2021). Habitat preservation efforts, such as bat roost conservation, can help protect natural roosting sites and reduce stress-induced viral shedding and the likelihood of pathogen spillover (Ruiz-Aravena et al., 2022). Vaccination strategies, such as rabies control programs in dogs and wildlife, can help eliminate human rabies cases while preserving carnivore populations (Akinsulie et al., 2024). These examples demonstrate that preserving ecosystems is not only an environmental priority but a pivotal public health strategy, underscoring biodiversity as a fundamental element in zoonosis prevention.

5 Conclusion

These paradoxes and dilemmas are not insurmountable conflicts but complex interconnected challenges requiring collaborative and systematic solutions.

5.1 An integrated approach to transform biophilia into opportunities for zoonosis prevention

Promoting responsible biophilia and biodiversity has the potential to reconcile the paradox between fostering human-nature connections and mitigating zoonotic risks, informing ethical decision-making that benefits human, animal, and ecosystem health. Integrating conservation efforts with sustainable natural resources management, ethical nature-based activities, and community-centered disease prevention strategies can help reduce the trade-offs between protecting biodiversity, safeguarding public health, and supporting local livelihoods. Instead of perceiving conservation and zoonosis prevention as disparate goals, an integrated approach emphasizes biodiversity as a primary mechanism for mitigating zoonotic risk while providing economic opportunities. Many existing cases have offered a feasible framework for people to coexist with nature safely and sustainably.

5.2 An equitable and just approach to build community-driven and culturally inclusive strategies for zoonosis prevention

Furthermore, the incorporation of cultural and social perspectives into conservation and zoonosis prevention strategies has been demonstrated to promote sustainable and community-driven solutions. Integrating local and traditional knowledge into local surveillance systems and resource management can promote ecological stewardship in ways that align with local cultural practices. Meanwhile, the implementation of culturally relevant risk communication strategies has demonstrated efficacy in fostering engagement and compliance by leveraging trusted local leaders, traditional storytelling, and community-led activities. These approaches ensure that solutions are not only scientifically sound but also acceptable, equitable, and sustainable to be capable of driving changes in the long term.

5.3 One Health principles as a guide for policymaking

These solutions will result from a paradigm shift in the development and implementation of zoonotic risk mitigation, transitioning from a siloed, discipline-specific, and academic process to a transdisciplinary, community-centered, and cross-sectoral collaboration. A One Health approach that recognizes the interconnections between people, animals, and ecosystems has the potential to encourage policies that balance human-nature connection and zoonotic risk management. These policies can guide various sectors, including urban planning, tourism, biosecurity measures, and other ethical and sustainable regulations in conservation and public health, acknowledging the value of biophilia. This approach is poised to foster collaborative efforts to break down the barriers between disciplines and sectors and transform the perceived paradoxes and dilemmas into synergies, resulting in solutions from short-term fixes to long-term resilience.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author/s.

Author contributions

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Editorial: Preventing zoonoses. Promoting biophilia

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Editorial on the Research Topic
Preventing zoonoses. Promoting biophilia

Introduction

Wild animals have an active role in the patterns of processes of most zoonoses – infectious diseases that can be transmitted between people and other animals (Kruse et al., 2004; Jones et al., 2008; Rahman et al., 2020). Throughout human history, infectious diseases originating in wild animals have had a profound impact on the evolution of *Homo sapiens* (Wolfe et al., 2007; Karesh et al., 2012). In the contemporary era, environmental degradation on a large spatio-temporal scales and the increasing globalization of trade and travel has led to a significant escalation in the threats posed by zoonoses to human, animal, and ecosystem health (Marano et al., 2007; Esposito et al., 2023). While enhancing public awareness to reduce the risks of zoonoses infection and spread is necessary, it can inadvertently instill or amplify fear of wildlife and the natural environment (biophobia). For instance, the increased reporting of zoonotic risks linked to bats, despite the rarity of human infection, has promoted a widespread biophobia towards bats, leading to the destruction of bat roosts and culling efforts that undermine both bat conservation and ecological health (Anderson and Reaser). There is a pressing need to strike a balance between public awareness of zoonotic risks and the promotion of biophilia – the innate human affinity for seeking positive connections with nature – to foster sustainable coexistence rather than fear-driven responses (Kirkey).

Recognizing that promoting biodiversity conservation through a positive human-nature relationship is a fundamental strategy for zoonosis prevention, this Research Topic explores the potential of integrating biophilia into zoonosis prevention efforts. By consciously and actively promoting biophilia, rather than biophobia, we can inspire a deeper appreciation for wild animals and the ecosystems they inhabit, thereby strengthening conservation efforts and, ultimately, addressing zoonotic risk at their source. Bringing together diverse perspectives and research, this Research Topic reports new scientific findings, catalyzes discussion, and provides practitioners with actionable insights bridging biodiversity conservation and public health.

The articles

The Research Topic opens with the Perspective “Wildlife culling as a biophobic response to zoonotic disease risk: why we need a One Health approach to risk communication” in which the authors establish the need for this Research Topic – well intended public health messaging aimed at preventing zoonotic outbreaks can instilled fear of wildlife (biophobia), leading to the wildlife culling and habitat destruction. The authors review several cases, including examples in which government agencies directed the mass killing of wildlife despite a lack of evidence that the species targeted was spreading the pathogens of concern (Anderson and Reaser).

The Perspective “What’s love got to do with it? A biophilia-based approach to zoonoses prevention through a conservation lens” provides something of an antidote to the fear-induced culling described in the previous article. The author proposes that public health communication strategies rooted in biophilia concepts may be more effective at generating empathy for both ecological and human communities, leading to greater willingness to leave zoonotic pathogen hosts and their habitats alone, further reducing spillover events and the ecological conditions that make spillover more likely (Kirkey).

During the SARS-CoV-2 pandemic, biophobic (aversive) responses towards bats were recorded in urban and rural areas of Mexico’s Yucatán Peninsula, making evident the need to monitor bat diversity, investigate species’ biology, and, perhaps most importantly, conduct educational activities that foster an affinity for bats. The authors’ Original Research described in “Ecological-based insights into bat populations in the Yucatán Peninsula under a One Health approach: coexistence or biophobia” establishes a baseline for zoonotic disease screening and prevention in the Yucatán Peninsula, as well as demonstrates the importance of coexistence with bats given their key role in maintaining the health of ecosystems (Sánchez-Soto et al.).

In the Policy and Practice Review “Protecting urban wildlife fauna, fighting zoonoses, and preventing biophobia in Brazil”, the authors explore how Curitiba, a Brazilian city, may serve as a model for a One Health approach enabling zoonoses prevention and biodiversity conservation to be achieved simultaneously. They place emphasis on the importance of nature connection (e.g., urban gardening) as an antidote to biophobia (Kmetiuk et al.).

“Veterinary clinicians as One Health messengers: opportunities for preventing zoonoses while promoting biophilia in the United States” is a Perspective on key constraints facing veterinarians as One Health communicators at the zoonotic disease/biodiversity conservation interface. Overcast proposes two solutions to integrate preventive zoonoses messaging and biophilia promotion within veterinary clinical practice: (1) the human-animal bond should be reconceptualized within veterinary clinical sciences as a community-level resource akin to natural capital, and (2) the veterinary extension workforce should be expanded to include agents facilitating local conservation and public health information exchange with companion animal veterinarians. The author’s intent is to empower veterinarians to communicate about zoonotic disease risks and conservation, ensuring that One Health principles are embedded in everyday clinical interactions and broader community initiative.

The paper “Application of the MENTOR model to advance One Health by promoting bat conservation and reducing zoonotic spillover risk” is a Perspective on an international fellowship program, MENTOR-Bat, that incorporates One Health and conservation within its activities to advance evidence-based strategies for improving the well-being of bats, humans, and the environment. Protecting bat populations and their habitats ultimately reduces biodiversity threats, helps prevent pandemics, and supports essential ecosystem services (Smith et al.).

The Perspective “Love Them & Leave Them: science-based rationale for a campaign at the public health-conservation interface” envisions a social marketing campaign that promotes coupled messaging on zoonoses prevention and biodiversity conservation. The authors’ aim is to encourage public health communicators to provide responsible messaging on wildlife that may host zoonotic pathogens while simultaneously inspiring people to respect – ideally protect – wildlife and wildlife habitats to support the health of ecological systems. In other words, love wildlife but leave it alone – thereby mitigating the risk of exposure to pathogens (Reaser et al.).

In the complementary Perspective “Art can provide a means for promoting biophilia as an aspect of zoonoses risk communication” the author makes the case for strategically employing art as an effective method to communicate zoonotic risk while promoting biophilia. She notes that employing art as a method of communication has been explored by various scientific fields but has not been sufficiently applied to infectious disease messaging (Beaumont).

“Responsible biophilia for zoonosis prevention through a cultural lens” reflects on the experience and existing knowledge of diverse human-wildlife interactions across cultures that are associated with zoonotic risks. The Perspective includes case studies that illustrate the interconnections between biophilia and zoonotic risk and explores integrated approaches to achieve both public health and conservation goals while considering culture and livelihood needs (Li).

Call to action

The potential for fear-driven responses to public information about wildlife-associated diseases presents challenges to biodiversity conservation and human health. Wildlife might be killed. Habitats might be destroyed. People might get infected while engaged in wildlife culling and habitat destruction. Zoonoses risk mitigation approaches that couple disease prevention goals with conservation goals are urgently needed. They are essential and must be sparked and informed by the essential relationship – the connection – between nature and human nature. Protecting public health necessitates that we acknowledge people as an aspect of natural systems and cycles. The healthier the planet, the healthier the planetary inhabitants.

The articles in this Research Topic make a strong case for greater awareness of biophilia-based zoonoses prevention. Further, they call for responsible public health communication that aims to safeguard biodiversity. Finally, this body of work reminds us of the importance of supporting conservation efforts that protect ecosystems and prevent the emergence of disease. Ultimately, this work reminds us that the health of people, wildlife, and the planet are deeply interconnected.

Author contributions

JR: Conceptualization, Supervision, Project administration, Writing – review & editing, Funding acquisition, Writing – original draft. HL: Writing – review & editing, Writing – original draft. IK: Writing – original draft, Writing – review & editing. TB: Writing – review & editing, Writing – original draft. SS: Writing – original draft, Writing – review & editing.

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